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Application Note

78K0 Series

Dual Slope A/D Conversion

8-bit Single-Chip Microcontrollers

Document No. U17157EE1V0AN00
Date Published May 2004

NOTES FOR CMOS DEVICES

① PRECAUTION AGAINST ESD FOR SEMICONDUCTORS

Note:

Strong electric field, when exposed to a MOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop generation of static electricity as much as possible, and quickly dissipate it once, when it has occurred. Environmental control must be adequate. When it is dry, humidifier should be used. It is recommended to avoid using insulators that easily build static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work bench and floor should be grounded. The operator should be grounded using wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions need to be taken for PW boards with semiconductor devices on it.

② HANDLING OF UNUSED INPUT PINS FOR CMOS

Note:

No connection for CMOS device inputs can be cause of malfunction. If no connection is provided to the input pins, it is possible that an internal input level may be generated due to noise, etc., hence causing malfunction. CMOS devices behave differently than Bipolar or NMOS devices. Input levels of CMOS devices must be fixed high or low by using a pull-up or pull-down circuitry. Each unused pin should be connected to V_{DD} or GND with a resistor, if it is considered to have a possibility of being an output pin. All handling related to the unused pins must be judged device by device and related specifications governing the devices.

③ STATUS BEFORE INITIALIZATION OF MOS DEVICES

Note:

Power-on does not necessarily define initial status of MOS device. Production process of MOS does not define the initial operation status of the device. Immediately after the power source is turned ON, the devices with reset function have not yet been initialized. Hence, power-on does not guarantee out-pin levels, I/O settings or contents of registers. Device is not initialized until the reset signal is received. Reset operation must be executed immediately after power-on for devices having reset function.

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Chapter 1 Introduction

This application note is written to describe an AD conversion procedure using the 78K0 / Kx1(+) microcontroller family products. The AD conversion is done using the dual slope method. It is performed with a minimum of external hardware components. Only three resistors and one capacitor are needed.

Chapter 2 Description of A/D Conversion Using the Dual Slope Method

Using the dual slope method a resistor value can be converted into a digital counter value.
To do this, the charging time of a capacitor will be measured with a timer of a microcontroller. The first charging slope will use a reference resistor (R_{REF}) and the second charging slope will use variable resistor or thermistor (R_{VAR}) which should be determined. By the comparison of the two measured times and the known reference resistor (R_{REF}) the variable resistor (R_{VAR}) can be calculated.

The 78K0 / Kx1(+) family has the advantage of bit settable I/O ports and Schmitt-trigger inputs (e.g. TI000). In this application the bit settable port 0 is used as a bidirectional port.
At first, the complete P0 is cleared and set to output mode. In this case the capacitor is discharged via P00/TI000 and prepared for the first measurement. The resistor R_P is only used to limit the current during the discharging of the capacitor. Then port 0.3 is set to 1 and output. At this point also the 16-bit capture timer is started. The rest of the port 0 is set to input (high impedance). So the capacitor will be charged via the reference resistor R_{REF}. When the capacitor has reached the threshold level of the Schmitt-trigger input P00/TI000, the actual timer value is automatically captured and an internal interrupt is generated. Using this interrupt the capture value is read out. Now the capacitor will be discharged again. The same procedure starts once more with port 0.2. This time the capacitor is charged via the unknown resistor R_{VAR} and after the threshold is reached again the second timer value is read out.
The unknown R_{VAR} can be calculated from the two values obtained using the method described above and the value of the reference resistor. (Please refer to derivation.)

Chapter 3 Derivation

$$R_{REF}: \; V_{CREF} = V_{DD}\left(1 - e^{-\frac{t_{REF}}{R_{REF} \times C}}\right)$$

$$R_{VAR}: \; V_{CVAR} = V_{DD}\left(1 - e^{-\frac{t_{VAR}}{R_{VAR} \times C}}\right)$$

$$V_C = V_{CVAR} = V_{CREF} = const$$

The threshold level of the Schmitt-trigger input does not have any influence on the accuracy of the measurement. As this will be a constant for both measurements.

$$V_{DD}\left(1 - e^{-\frac{t_{REF}}{R_{REF} \times C}}\right) = V_{DD}\left(1 - e^{-\frac{t_{VAR}}{R_{VAR} \times C}}\right)$$

$$1 - e^{-\frac{t_{REF}}{R_{REF} \times C}} = 1 - e^{-\frac{t_{VAR}}{R_{VAR} \times C}}$$

$$e^{-\frac{t_{REF}}{R_{REF} \times C}} = e^{-\frac{t_{VAR}}{R_{VAR} \times C}}$$

$$\frac{t_{REF}}{R_{REF} \times C} = \frac{t_{VAR}}{R_{VAR} \times C}$$

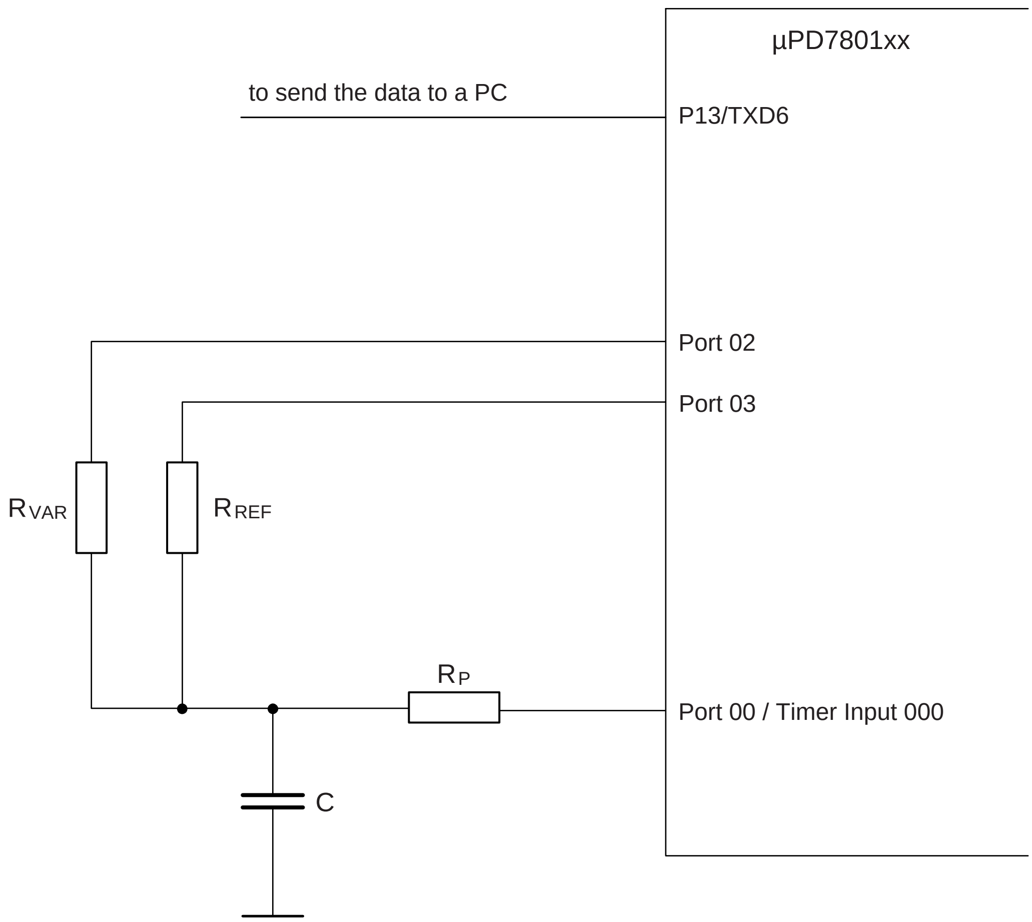
$$\frac{t_{REF}}{R_{REF}} = \frac{t_{VAR}}{R_{VAR}}$$

$$R_{VAR} = R_{REF} \times \frac{t_{REF}}{t_{VAR}}$$

C and V_{DD} do not have any influence on the accuracy of the measurement. Only the absolute value of the reference resistor R_{REF} has an influence, because these parameters will not change during one measurement. Using the R_{REF}, t_{REF} and t_{VAR}, the resistor R_{VAR} can be calculated.

Chapter 4 Circuit Diagram

Figure 4-1: Circuit Diagram



Port 03 is used to charge the capacitor via the reference resistor R_{REF}. Port 02 is used to charge the capacitor via the unknown resistor R_{VAR}. The time of charging the capacitor is measured in both cases.
Port 00 / TI000 is used as a capture input for the timer. This port has a Schmitt-trigger behaviour. Additionally this port is used to discharge the capacitor. The protection resistor R_P will limit the discharging current and must be considered for the discharge time.
Port 13 is used as output. This pin is shared with the transmit pin of the UART6, and used to send the measured data to a PC (terminal program).

5.1 Calculation of Charging Time and Timer Setup

5.1.1 Charging time

$$V_C = V_{DD}\left(1 - e^{-\frac{t}{R \times C}}\right)$$

$$\frac{V_C}{V_{DD}} = 1 - e^{-\frac{t}{R \times C}}$$

$$1 - \frac{V_C}{V_{DD}} = e^{-\frac{t}{R \times C}}$$

$$-\frac{t}{R \times C} = \ln\left(1 - \frac{V_C}{V_{DD}}\right)$$

$$t = -R \times C \times \ln\left(1 - \frac{V_C}{V_{DD}}\right)$$

Example:

V_{DD} = 5 V; $V_{threshold}$ = V_C = (0.4 …0.7) V_{DD}

Typical $V_{threshold}$ = 0.6 V_{DD}

R_{REF} = 51KΩ; C = 220 nF

$t = - R_{REF} \times C \times \ln (1-V_C/V_{DD})$

t_{TYP} = -51KΩ × 220 nF × ln (1 - 0.6)

t_{TYP} = 10.28 ms

5.1.2 Timer setup

Max setup time:

t_{MAX} = -51KΩ × 220 nF × ln (1 - 0.7)
t_{MAX} = 13.5 ms

Resolution:

Resolution = t_{MAX} / step time

With the 16-bit capture timer of the 78K0 / Kx1(+) family a resolution of 400 ns (f_X/4 @10 MHz) can be realized. Thus the reached resolution will be:

Resolution = t_{MAX} / 400 ns
= 13.5 ms / 400 ns
= 33750 steps

Thus in this application note a resolution of about 15 bit is used. Due to the max timer resolution of 16-bit (65536 steps) a higher or a lower resolution can be realized.

Note: It is recommended that the value of the resistors R_{REF} and R_{VAR} should be in a range between 10 KΩ and 100 KΩ.
Lower resistors than 10 KΩ may result a lower accuracy due to the voltage drop (V_{OH} = f (I_{OH})).
Higher resistor values than 100 KΩ might cause a lower accuracy due to some leakage current.

Chapter 6 Software

The software consists of the following three modules.

6.1 Main

This module contains the system initialization and the main loop.
CPU clock, all ports, the used 16-bit timer and the UART will be initialized. In the main loop the conversion is started, the result converted and the transmission module was called.

6.2 Measurement

This module will do a complete dual slope measurement.
This is in detail:

- Discharging the capacitor.
- Reference measurement using R_{REF}.
- Store the result for the reference resistor.
- Discharging the capacitor.
- Absolute measurement using R_{VAR}.
- Store the result for the variable resistor.

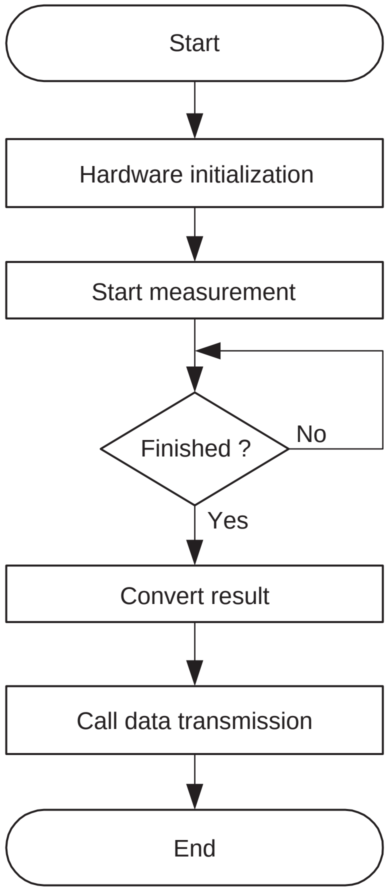
6.3 Data Transmission

This module converts the measured data to an ASCII format and sends it via UART. Using this module the measured data can be displayed on a PC using a terminal program.

Chapter 7 Software Flowcharts

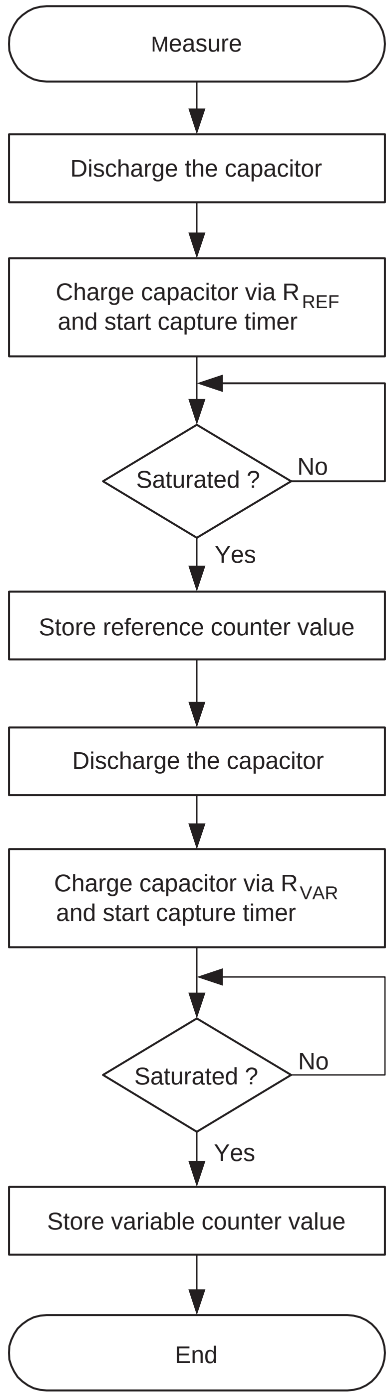
7.1 Main Routine

Figure 7-1: Main Flow



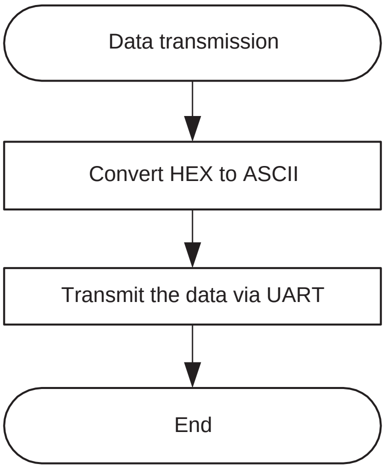
7.2 Measurement Function

Figure 7-2: Measurement Flow



7.3 Data Transmission

Figure 7-3: Data Transmission Flow



Chapter 8 Listing

```
/*==============================================================
** PROJECT      = dual slope.c
** MODULE       =
** VERSION      = 0.0
** DATE         = 3.05.2004
** LAST CHANGE  =
** **==============================================================
** Description:
**
**==============================================================
** Environment: Device:         uPD78F014x
**              Assembler:      A78000         Version
**              C-Compiler:     ICC78000       Version
**              Linker:         XLINK          Version
**
** **==============================================================
** By:               NEC Electronics (Europe) GmbH
**                   Arcadia Strasse 10
**                   D-40472 Duesseldorf
**
**                   NEC-EE, CES
** **==============================================================
Changes:
**==============================================================
*/

/*==============================================================
** pragma
**==============================================================
*/
#pragma language = extended

/*==============================================================
** include
**==============================================================
*/
#include "DF0148.h"
#include <in78000.h>

/*==============================================================
** type definitions (function prototypes)
**==============================================================
*/


/*==============================================================
** import list
**==============================================================
*/
```

```
/*==============================================================
** define
**==============================================================
*/
/* mode register definitions */

/* interrupt register definitions */

/* constant definitions */

/*=============================================================
** variable definitions
**=============================================================
*/

saddr unsigned int ref_time, meas_time;
saddr unsigned long calc_value;
saddr unsigned char ds_status;

bit DS_Ready, DS_OVF_error, sendokflag;

/*==============================================================
** variable init
**==============================================================
*/

void hdwinit (void)
{
// clock generator setting
   PCC  = 0x00;            // switch with speed
   OSTS = 0x05;
   MOC = 0x00;             // start main osc.

   // port setting
   PM0  = 0x70;            // port 0  = output
   PM1  = 0x00;            // port 1  = output
   PM3  = 0xF0;            // port 3  = output
   PM4  = 0x00;            // port 4  = output
   PM5  = 0x00;            // port 5  = output
   PM6  = 0x00;            // port 6  = output
   PM7  = 0x00;            // port 7  = output
   PM12 = 0xFE;            // port 12 = output
   PM14 = 0xC0;            // port 14 = output
   PU0  = 0x70;            // no pull up-resistors
   PU1  = 0x00;            // no pull up-resistors
   PU3  = 0xF0;            // no pull up-resistors
   PU4  = 0x00;            // no pull up-resistors
   PU5  = 0x00;            // no pull up-resistors
   PU6  = 0x00;            // no pull up-resistors
   PU7  = 0x00;            // no pull up-resistors
   PU12 = 0xFE;            // no pull up-resistors
   PU14 = 0xC0;            // no pull up-resistors
```

```
   P14.1 = 1;
   P14.0 = 0;               // to enable RS232 on play it

   //LVIE=1;

   while (!OSTC.4)
    {
    WDTE=0xAC;              // reset watchdog
    _NOP();
    }
   MCM0 = 1;                // set cpu-clock = main osc.

   ISC  = 0x00;             // Input control

// watchdog timer setting
   WDTM = 0x77;             // Watchdog off


// A/D setting 1


// interrupt setting
   IF0L  = 0x00;
   IF0H  = 0x00;
   IF1L  = 0x00;
   MK0L  = 0xFF;
   MK0H  = 0xFF;
   MK1L  = 0xFF;


// 8-bit timer setting


//16-bit timer setting
   TMC00 = 0x00;         // operation stop
   PRM00 = 0x11;         // clock frequency 2.5MHz
                         // TI000 rising edge
   CRC00 = 0x04;         // CR010 operates as capture register
   TOC00 = 0x00;         // no timer-output
   TMIF010 = 0;          // reset interruptflag


//Uart6 setting
   CKSR6 = 0x02;          // clock selection 2.5MHz
   BRGC6 = 0x82;          // baud rate 9600
   ASIM6 = 0x81;          // Power-up UART6

// error with receive-interrupt
   ASIM6 = 0xC5;          // transmit enable 8,n,1
   STMK6 = 0;             // transmit interrupt enable
   SRMK6  = 1;            // receive interrupt disable
   P1.3 = 1;              // enable TX-function
   PM1.3 = 0;             // enable TX-output
}
```

```
callt void discharge_C (void)
 {
  unsigned int i;

  PM0 &= 0XF2;           // switch all ports to output
  P0 &= 0xF2;            // discharge C
  for (i=0;i<2000;i++)  // wait for discharging the capacitor
   {
   _NOP();
   };
 }


callt void senddata (unsigned long data)
{
   sendokflag=0;
   TXB6 = ':';
   while (!sendokflag);
   sendokflag=0;
   TXB6 = ((data/100000)%10)+'0';
   while (!sendokflag);
   sendokflag=0;
   TXB6 = ((data/10000)%10)+'0';
   while (!sendokflag);
   sendokflag=0;
   TXB6 = ((data/1000)%10)+'0';
   while (!sendokflag);
   sendokflag=0;
   TXB6 = ((data/100)%10)+'0';
   while (!sendokflag);
   sendokflag=0;
   TXB6 = ((data/10)%10)+'0';
   while (!sendokflag);
   sendokflag=0;
   TXB6 = (data%10)+'0';
   while (!sendokflag);
   sendokflag=0;
   TXB6 = 0x0D;
   while (!sendokflag);
}


interrupt [INTST6_vect] void transmit (void)
{
   sendokflag = 1;
}


interrupt[INTTM010_vect] void timer01(void)
{
 unsigned int CR_value;

 CR_value = CR010;
 TMC00 = 0x00;           // stop and clear timer
```

```
 switch(ds_status)
  {
   case 0:              // start of dualslope conversion with
                        // discharging the C
    discharge_C();
    PM0 |= 0x05;
    P0.3 = 1;           // set reference resistor port to high
                        // level
    TMC00 = 0x06;       // start free running-mode
    ds_status++;
    break;

   case 1:              // start of dualslope 2. conversion with
                        // discharging the C
    if (OVF00)          // if overflow flag is set measurement is
                        // invalid
     {
        DS_Ready=1;
        DS_OVF_error=1;
        ds_status=0;
     }
    else
     {
      ref_time = CR_value;
      discharge_C();
      PM0 |= 0x09;
      P0.2 = 1;         // set var. resistor port to high level
      TMC00 = 0x06;     // start free running-mode
      ds_status++;
     }
     break;

   case 2:              // end of dualslope conversion calculating
                        // value
    if (OVF00)          // if overflow flag is set measurement is
                        // invalid
     {
        DS_OVF_error=1;
     }
    else
     {
      meas_time = CR_value;
      PM0 &= 0xFE;      // enable discharge
      P0 &= 0xFE;
      TMMK010 = 1;      // conversion disabled
     }
      ds_status=0;      // reset dual slope status
      DS_Ready=1;       // conversion finished
     break;
  }
}
```

```
/* ================================================================
** main function
** ================================================================
*/

void main (void)
{
 unsigned int i;
  _DI();          // interrupt disable
  hdwinit ();     // peripheral settings
 _EI();           // interrupt enable


ds_status = 0;    // initialize dual-slope flags and status-
                  // counter
 DS_Ready = 0;
 DS_OVF_error = 0;

 TMMK010 = 0;     // start conversion by enabling the timer
                  // interrupt and setting the interrupt flag
 TMIF010 = 1;


  while(1)        // endless loop - main loop
  {

   if (DS_Ready)
    {
       if (!DS_OVF_error)
      {
         calc_value=51000*meas_time/ref_time;      // calculate value
                                                   // here reference
                                                   // resistor = 51k
         senddata(calc_value);                     // send data via
                                                   // UART
      }
     ds_status = 0;            // initialize dual-slope flags and
                               // status-counter
     DS_Ready = 0;
     DS_OVF_error = 0;
     TMMK010 = 0;              // start conversion
     TMIF010 = 1;

    }
  for (i=0;i<50000;i++)        // foreground process
   {
    _NOP();
    };

  }
}
```

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