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## **Application Note**

# **78K0 Series**

## **Dual Slope A/D Conversion**

### **8-bit Single-Chip Microcontrollers**

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## 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(+) micro-controller 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

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

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

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

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.

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

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

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

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

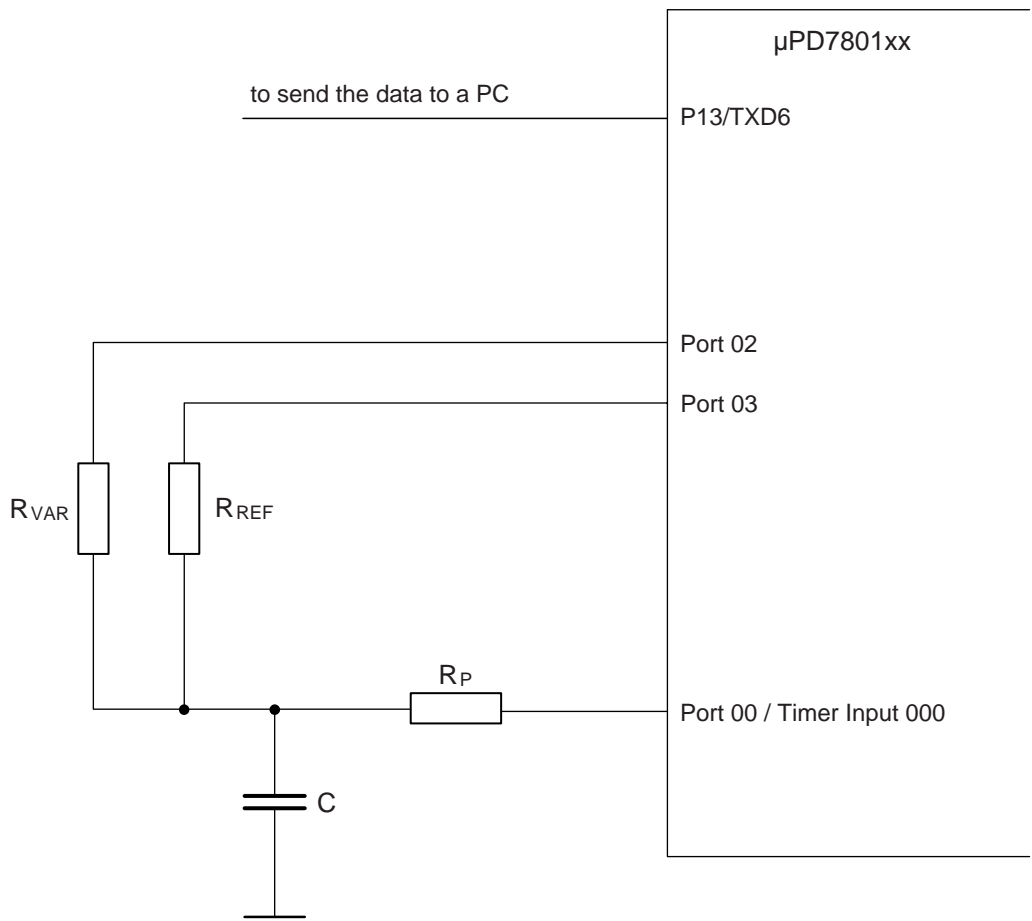
$$\frac{t_{REF}}{R_{REF}} = \frac{t_{VAR}}{R_{VAR}}$$

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

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



## Chapter 5 Hardware

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

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

#### Example:

$$V_{DD} = 5 \text{ V}; V_{\text{threshold}} = V_C = (0.4 \dots 0.7) V_{DD}$$

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

$$R_{REF} = 51 \text{ K}\Omega; C = 220 \text{ nF}$$

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

$$t_{\text{TYP}} = -51 \text{ K}\Omega \times 220 \text{ nF} \times \ln (1 - 0.6)$$

$$t_{\text{TYP}} = 10.28 \text{ ms}$$

### 5.1.2 Timer setup

#### Max setup time:

$$\begin{aligned}t_{MAX} &= -51K\Omega \times 220 \text{ nF} \times \ln(1 - 0.7) \\t_{MAX} &= 13.5 \text{ ms}\end{aligned}$$

#### Resolution:

$$\text{Resolution} = t_{MAX} / \text{step time}$$

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:

$$\begin{aligned}\text{Resolution} &= t_{MAX} / 400 \text{ ns} \\&= 13.5 \text{ ms} / 400 \text{ ns} \\&= 33750 \text{ steps}\end{aligned}$$

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 K $\Omega$  and 100 K $\Omega$ .  
Lower resistors than 10 K $\Omega$  may result a lower accuracy due to the voltage drop ( $V_{OH} = f(I_{OH})$ ).  
Higher resistor values than 100 K $\Omega$  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.

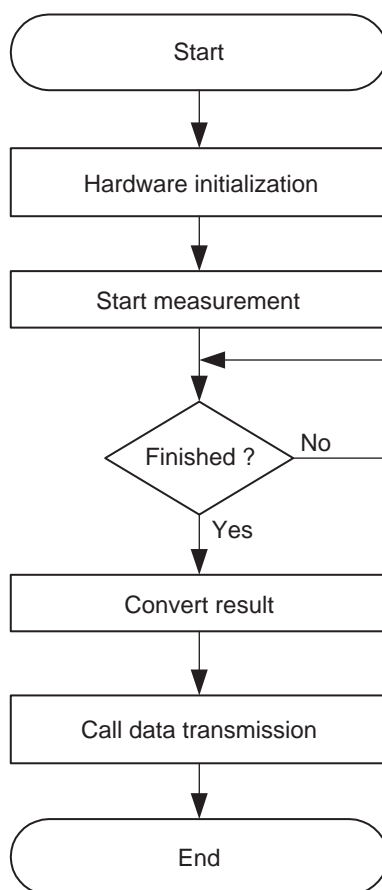
### 6.3 Data Transmission

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

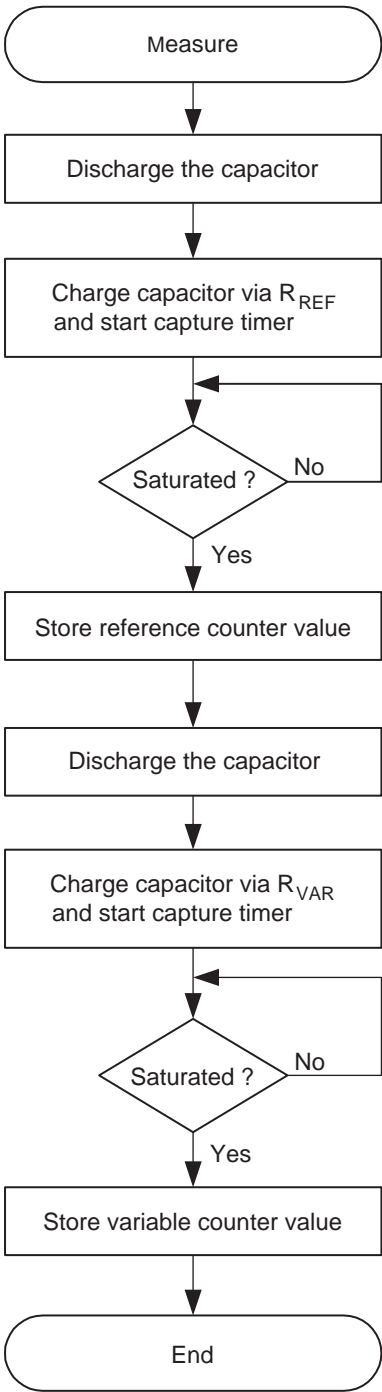
**Figure 7-1: Main Flow**





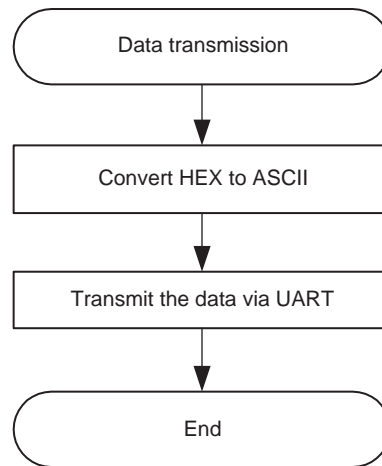
7.2 Measurement Function

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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