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Application Note

V850 Series

Dual Slope A/D Conversion

32-bit Single-Chip Microcontrollers

Document No. U17227EE1V0AN00
Date Published June 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 V850ES / Fx2 microcontroller family products. Other derivates of the V850 series can also be supported by minor changes of the source code. 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 V850ES / Fx2 family has the advantage of bit settable I/O ports and Schmitt-trigger inputs (e.g. P32/TIP00). In this application the bit settable port P3 is used as a bidirectional port.
At first, the port P32/TI00 is cleared and set to output mode. In this case the capacitor is discharged 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 P33 is set to 1 and output. At this point also the 16-bit capture timer is started. The rest of the port P3 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 P32/TIP00, 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 P34. 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.

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

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

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

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

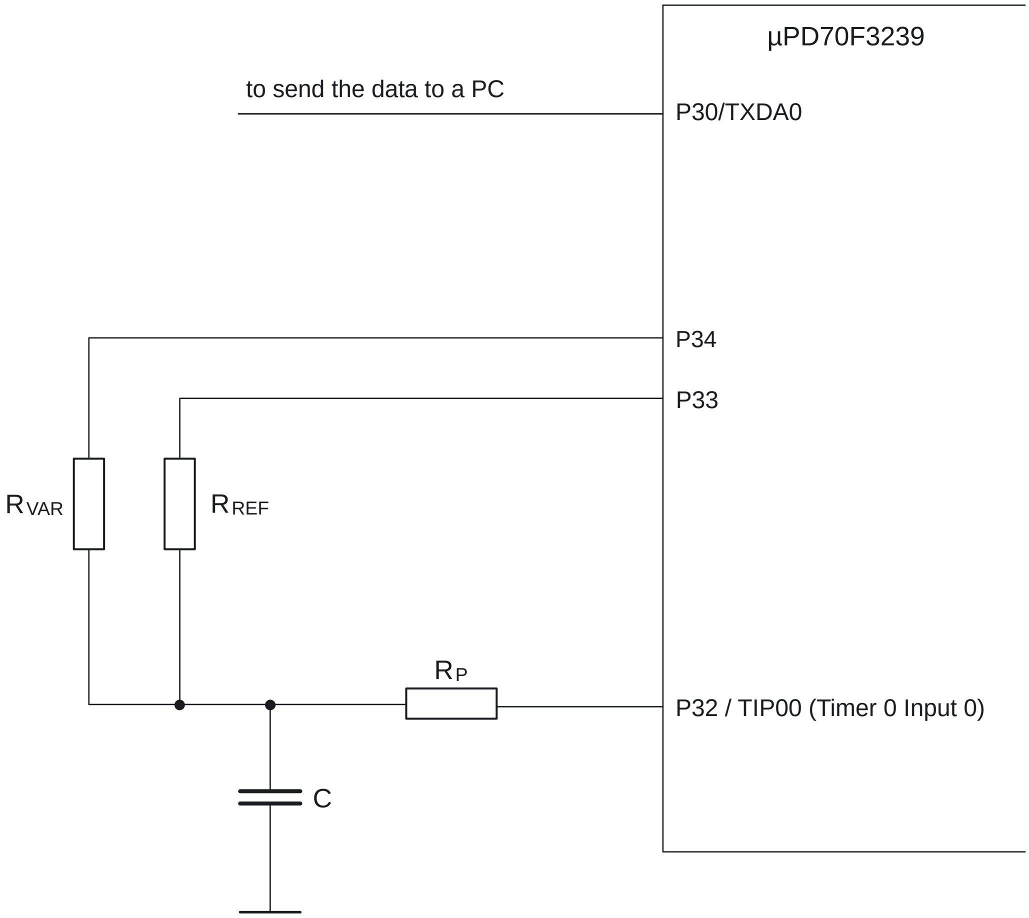
$$\frac{t_{REF}}{R_{REF}} = \frac{t_{VAR}}{R_{VAR}}$$

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

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



Chapter 5 Hardware

Port P33 is used to charge the capacitor via the reference resistor R_{REF}. Port P34 is used to charge the capacitor via the unknown resistor R_{VAR}. The time of charging the capacitor is measured in both cases.
Port 32 / TIP00 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 30 is used as output. This pin is shared with the transmit pin of the UARTA, 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; $V_{threshold} = V_C = (0.4 \ldots 0.7)\ V_{DD}$

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

R_{REF} = 51 KΩ; C = 220 nF

R_P = 100 Ω

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

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

t_{TYP} = 10.28 ms

5.1.2 Timer setup

Max setup time:

t_{MAX} = -51 KΩ × 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 V850ES / Fx2 family a resolution of 50 ns (f_{XX} @20 MHz) can be realized. Thus the reached resolution will be:

Resolution = t_{MAX} / 50 ns
= 13.5 ms / 50 ns
= 270.000 steps

This amount of steps would generate an overflow of the 16-bit timer (65536 steps). So, the timer prescaler is set to a resolution of 200 ns (f_{XX}/4 @20 MHz).Then the reached resolution will be:

Resolution = t_{MAX} / 200 ns
= 13.5 ms / 200 ns
= 67.500 steps

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

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.

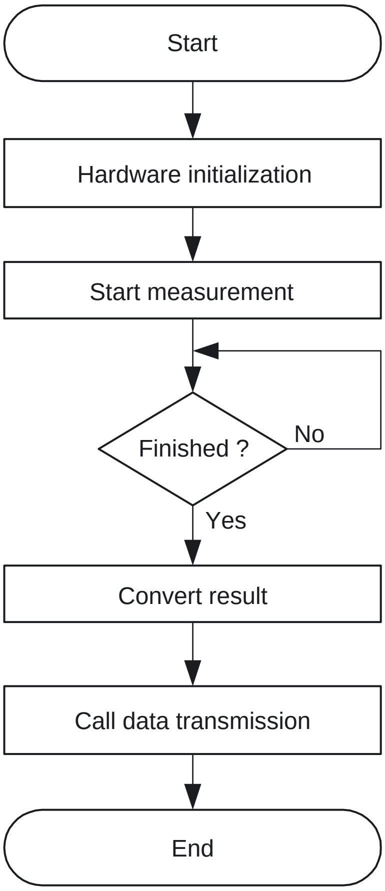
6.3 Data Transmission

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

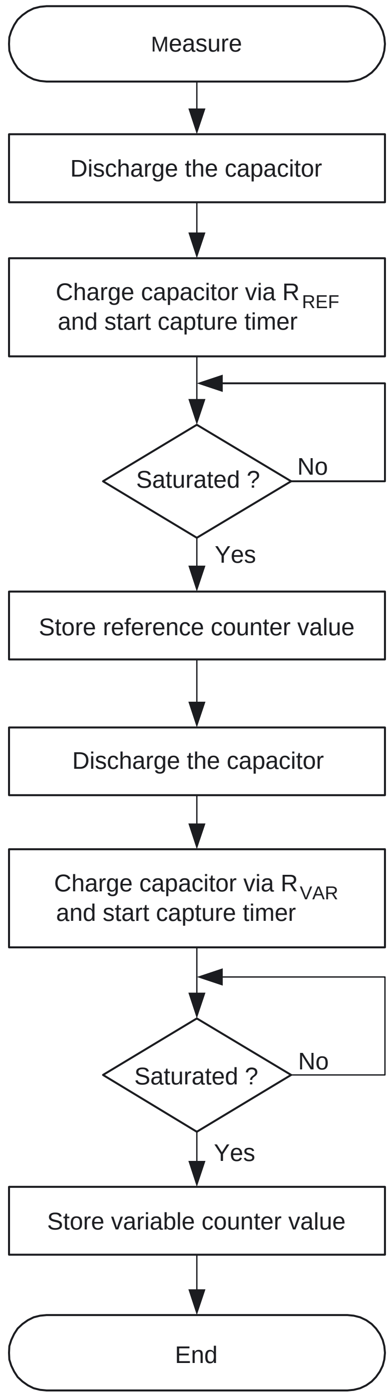
7.1 Main Routine

Figure 7-1: Main Flow



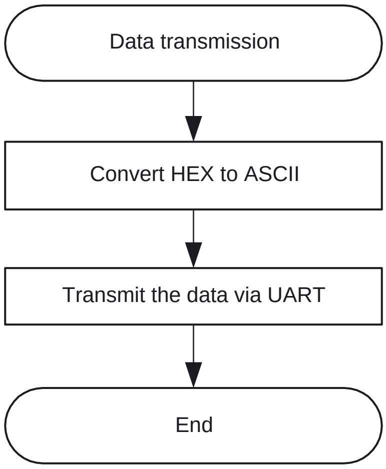
7.2 Measurement Function

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: Demoprorgam for dual slope emulation
**
**==============================================================
** Enviroment:  Device:         uPD70F3239
**              C-Compiler:     Green Hills    Version 3.5.1
**
**==============================================================
** By:               NEC Electronics (Europe) GmbH
**                   Arcadia Strasse 10
**                   D-40472 Duesseldorf
**
**                   NEC-EE, CES
**==============================================================
Changes:
**==============================================================
*/

/*==============================================================
** include
**==============================================================
*/
#include "df3239.h"
#include "df3239extIO.h"

/*==============================================================
** type definitions
**==============================================================
*/
typedef enum { false = 0, true = 1 } bit;


/*==============================================================
** definitions
**==============================================================
*/
/* Reference resistor value */
#define REF_RESISTOR            56000

/* Loop constant for discharging C */
#define WAITLOOP                2000


/* macros for portpin switching */
#define TM_PORT                 ((volatile struct bitf *)(&P3))->bit02
#define TM_PORT_MODE            ((volatile struct bitf *)(&PM3))->bit02
#define TM_PORT_MODE_CONTROL    ((volatile struct bitf *)(&PMC3))->bit02
#define REF_PORT                ((volatile struct bitf *)(&P3))->bit03
#define REF_PORT_MODE           ((volatile struct bitf *)(&PM3))->bit03
```

```
#define VAR_PORT                ((volatile struct bitf *)(&P3))->bit04
#define VAR_PORT_MODE           ((volatile struct bitf *)(&PM3))->bit04

/* macros for starting and stopping the timer */
#define Timer_Start()      (((volatile struct bitf *)&(TP0CTL0))->bit07 = 1)
#define Timer_Stop()       (((volatile struct bitf *)&(TP0CTL0))->bit07 = 0)


/* State machine defines for timer ISR */
#define DISCHARGE_STATE         0
#define REF_CONV_STATE          1
#define MEASUREMNT_STATE        2


/*===============================================================
** variable definitions
**===============================================================
*/
unsigned int    ref_time, meas_time, calc_value;
unsigned char   DS_status;
bit             DS_Ready, DS_OVF_error, sendokflag;


/* ------------------------------------------------------------------ */
/* Hardware initialization                                              */
/* ------------------------------------------------------------------ */
void hdwinit (void) {

    /* Basic configuration for µPD70F323x */
    VSWC    = 0x01;     /* Peripheral wait states as recommended in manual */

    PRCMD  = 0x00;     /* Prepare to write specific register */
    PCC    = 0x00;     /* Select cpu clock fxx = foscl       */

    WDTM2   = 0x1f;     /* Stop watchdog timer                            */
    RCM     = 0x01;     /* Stop ring oscillator                           */
    PLLCTL  = 0x03;     /* F-Line CPUs have a PLL -> fxx = Osc_Freq * 4  */

    /* Port setting; Set all unused port to output to avoid floating */
    PM0    = 0x00;
    PM1    = 0x00;
    PM3H   = 0x00;
    PM4    = 0x00;
    PM5    = 0x00;
    PM6    = 0x0000;
    PM7L   = 0x00;
    PM7H   = 0x00;
    PM8    = 0x00;
    PM9    = 0x0000;
    PM12   = 0x00;
    PMDL   = 0x0000;
    PMCS   = 0x00;
    PMCT   = 0x00;
    PMCM   = 0x00;
    PMCD   = 0x00;
```

```
    /* Configure ports for dualslope */
    P3L    = 0x0C;   /* REF_PORT, VAR_PORT =1;  TM_PORT=0 */
    PM3L   = 0xFA;   /* REF_PORT, VAR_PORT =input;  TM_PORT=output */
    PMC3L  = 0x01;   /* TXDA0 output; TM_PORT=I/O(not peripheral) */
    PFC3L  = 0x00;   /* P32 = TIP00 */
    PFCE3L = 0x04;   /*      "      */

    /* 16-bit timer setting */
    //TP0CTL0  = 0x01;  /* fxx/2   */
    //TP0CTL0  = 0x02;  /* fxx/4   */
    TP0CTL0  = 0x03;    /* fxx/8   */
    //TP0CTL0  = 0x04;  /* fxx/16  */
    //TP0CTL0  = 0x05;  /* fxx/32  */
    //TP0CTL0  = 0x06;  /* fxx/64  */
    //TP0CTL0  = 0x07;  /* fxx/128 */
    TP0CTL1  = 0x05;    /* Free running mode */
    TP0IOC0  = 0x00;    /* No output */
    TP0IOC1  = 0x01;    /* Rising edge input */
    TP0IOC2  = 0x00;    /* No edge detection */
    TP0OPT0  = 0x10;    /* TP0CCR00 as capture register */
    TP0CCIC0 = 0x00; /* Enable Timer P0 capture int. 0; Priority 0 */
    TP0OVIC  = 0x00; /* Enable Timer P0 overflow err. int.; Priority 0 */

    /*UARTA0 setting */
    UA0CTL0 = 0xD2; /* Enable,Trans.,LSB first,8bit,no parity,1stop */
    UA0CTL1 = 0x02; /* 38400 bps @ 20 MHz  Error: 0.16% */
    UA0CTL2 = 65;   /*                 "               */
    UA0TIC  = 0x07; /* Enable transmit interrupt; priority 7 (lowest) */
}


/* ---------------------------------------------------------------------- */
/* Discharging capacitor for starting measurement                         */
/* ---------------------------------------------------------------------- */
void discharge_C (void) {
    unsigned int i;

    REF_PORT_MODE        = 1;  /* Switch reference port to Hi-z(Input)*/
    VAR_PORT_MODE        = 1;  /* Switch variable port to Hi-z(Input) */

    TM_PORT_MODE_CONTROL = 0; /* Switch port pin to I/O              */
    TM_PORT              = 0; /* Switch port pin to 0 -> Discharge C */

    for (i=0;i<WAITLOOP;i++) { /* Wait for discharging the capacitor  */
        __asm("nop");          /*    Waste time ...                   */
    }

    TM_PORT_MODE_CONTROL = 1;  /* Switch port pin to timer input      */
 }


/* ---------------------------------------------------------------------- */
/* Send data via UARTA0 as decimal value                                  */
/* ---------------------------------------------------------------------- */
void senddata(unsigned int data) {
    sendokflag = false;
    UA0TX = ':';
    while (sendokflag == false);
```

```
    sendokflag = false;
    UA0TX = ((data/100000)%10)+'0';
    while (sendokflag == false);
    sendokflag = false;
    UA0TX = ((data/10000)%10)+'0';
    while (sendokflag == false);
    sendokflag = false;
    UA0TX = ((data/1000)%10)+'0';
    while (sendokflag == false);
    sendokflag = false;
    UA0TX = '.';    /* decimal point -> xxx.xxx */
    while (sendokflag == false);
    sendokflag = false;
    UA0TX = ((data/100)%10)+'0';
    while (sendokflag == false);
    sendokflag = false;
    UA0TX = ((data/10)%10)+'0';
    while (sendokflag == false);
    sendokflag = false;
    UA0TX = (data%10)+'0';
    while (sendokflag == false);
    sendokflag = false;
    UA0TX = 0x0D;
    while (sendokflag == false);
}


/* ---------------------------------------------------------------------- */
/* Send data via UARTA0 as decimal value                                   */
/* ---------------------------------------------------------------------- */
void sendstring(const char *str) {
    while (*str) {
        sendokflag = false;
        UA0TX = *str++;
        while (sendokflag == false);
    }
}


/* ---------------------------------------------------------------------- */
/* UARTA0 transmission end interrupt service routine                       */
/* ---------------------------------------------------------------------- */
__interrupt void INTUA0T(void) {
    sendokflag = true;
}


/* ---------------------------------------------------------------------- */
/* Timer P0 overflow interrupt service routine                             */
/*   State machine for dualslope measurement                               */
/* ---------------------------------------------------------------------- */
__interrupt void INTTP0OV(void) {
    Timer_Stop();           /* Stop and clear timer         */
    DS_OVF_error = true;    /* Set overflow error flag      */
    DS_Ready     = true;    /* Indicate end of conversion   */
}
```

```
/* ---------------------------------------------------------------------- */
/* Timer P0 capture 0 interrupt service routine                            */
/*   State machine for dualslope measurement                               */
/* ---------------------------------------------------------------------- */
__interrupt void INTTP0CC0(void) {
    unsigned int CR_value;

    CR_value = TP0CCR0;     /* Read captured timer value */
    Timer_Stop();           /* Stop and clear timer      */

    switch(DS_status) {

        case DISCHARGE_STATE:     /* Start of reference measurement */
            discharge_C();        /*   Discharging C */
            REF_PORT      = 1;    /*   Set ref. resistor port to high */
            REF_PORT_MODE = 0;    /*                  "               */
            Timer_Start();        /*   Start timer */
            DS_status = REF_CONV_STATE;
            break;

        case REF_CONV_STATE:      /* Start of 2. conversion */
            ref_time = CR_value;
            discharge_C();        /*   Discharging C */
            VAR_PORT      = 1;    /*   Set var. resistor port to high */
            VAR_PORT_MODE = 0;    /*                   "              */
            Timer_Start();        /*   Start timer */
            DS_status = MEASUREMNT_STATE;
            break;

        case MEASUREMNT_STATE:    /* End of dualslope conversion  */
            meas_time     = CR_value;
            VAR_PORT_MODE = 1;    /*   Var. res. port to Hi-z(Input)*/
            DS_Ready      = true; /*   Conversion finished */
            break;
        }
}




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

void main(void) {

    //DI();         /* Interrupt disable   */
    hdwinit ();     /* Peripheral settings */
    EI();           /* Interrupt enable    */

    /* Initialize dual-slope flags and status-counter */
    DS_status    = DISCHARGE_STATE;
    DS_Ready     = false;
    DS_OVF_error = false;

    /* Start conversion by enabling the timer interrupt     */
    /* and setting the interrupt flag; Priority 0 (highest) */
```

```
    TP0CCIC0 = 0x80;

    while(1) {      /* Endless loop - Main loop */

        if (DS_Ready) { /* Conversion finished */

            if (DS_OVF_error == false) {
                /* Calculate value here reference resistor = 51k */
                calc_value = REF_RESISTOR * meas_time / ref_time;
                /* Send data via UART */
                senddata(calc_value);

            } else {    /* Timer overflow error */
                if (DS_status == REF_CONV_STATE)
                    sendstring("Reference error\r");
                else /* DS_status == MEASUREMNT_STATE */
                    sendstring("Measurement error\r");
            }

            /* Initialize dual-slope flags and status-counter */
            DS_status    = DISCHARGE_STATE;
            DS_Ready     = false;
            DS_OVF_error = false;

            /* Start conversion */
            TP0CCIC0 = 0x80;
        }


        /* . . .                                                        */
        /* Do anything while conversion is in background progress ... */
        /* . . .                                                        */

    }
}
```

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