AN2326
Application note

Calibrating the RC oscillator of the ST7ULTRALITE MCU using the mains

Introduction

The ST7ULTRALITE microcontroller contains an internal RC oscillator which can be trimmed to a specific frequency with the required accuracy. The oscillator frequency has to be calibrated by software using the RCCR register (RC Control Register) and the SICSR register (System Integrity Control/Status Register). The value entered in the RCCR/SICSR registers will switch ON a corresponding number of resistors that will modify the oscillator frequency. Whenever the ST7ULTRALITE microcontroller is reset, the 10-bit value contained in the RCCR/SICSR registers is restored to its default value (3FFh) i.e. the lower possible frequency, so each time the device is reset, you have to load the calibration value in the RCCR/SICSR registers. There are predefined calibration values stored in memory (refer to the" Internal RC Oscillator Adjustment" section in the ST7ULTRALITE datasheet). You can load one of these values in the RCCR/SICSR registers if one of the operating conditions matches that in your application. Otherwise, you can define your own value, store it in non volatile memory and load it in the RCCR/SICSR registers after each reset. However, if any of the external conditions (temperature or voltage, for instance) changes too drastically, the stored value may no longer produce the required accuracy. One solution is to recalculate the RCCR/SICSR register values after each reset, based on an external reference.

The purpose of this application note is to present a software solution using the frequency of the European standard mains (220V/50Hz) as a timebase to adjust the internal RC oscillator of the ST7ULTRALITE to 8 MHz. The same approach can also be used for the US mains standard (110V/60Hz).

The basic software takes less than 200 ms to calibrate the oscillator and uses less than128 bytes of program memory and five bytes of RAM for its simplest version. These RAM bytes can be freed for other purposes when the calibration is done. Another example using averages is given in this application note. This can be useful with noisy mains.

This application note also contains the diagram of a low cost circuit which converts the mains into a 5 volt power supply and protects the microcontroller from overcurrent on the input connected to the mains.

Contents

1 Calibration software

1.1 Software principle

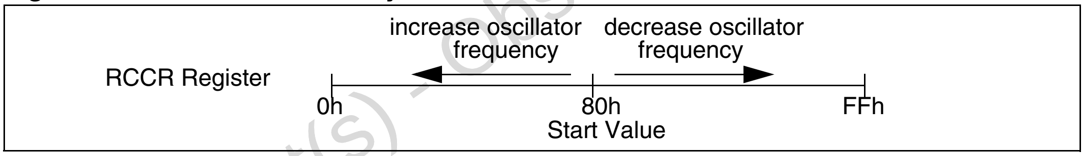
The software algorithm, described in the following flowchart (see Figure 3.), uses the mains frequency as a timebase. This timebase allows the microcontroller to test if the RC oscillator frequency is above or below the targeted frequency and repeatedly transforms it by dichotomous analysis so that in 10 iterations the RCCR/SICSR registers are set to the optimum value. In order to simplify the calculation, the calibration is done at 1MHz, the 8MHz internal RC is divided by 8 thanks to the AVTCHR register.

As the timer speed depends on the RC oscillator frequency, it is easy to determine if the oscillator is too fast or too slow. The counted value can be obtained by the following equation:

$$\text{countedvalue} = \frac{f_{cpu}}{32 \times f_{mains}}$$

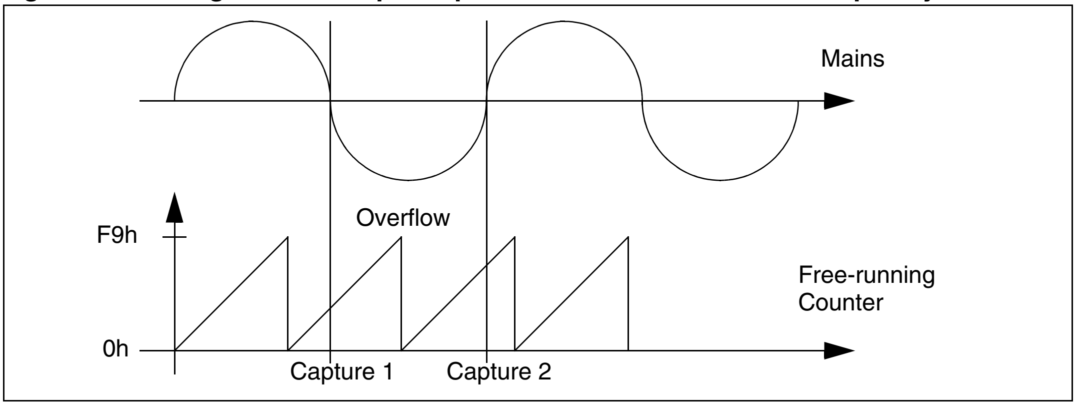
Since the frequency of the counter is the frequency of the oscillator divided by 32 (only the 8 MSbits are saved on the 13 bits of the counter), if the oscillator is at 1 MHz, the result of the count between two edges (which have a 10 ms interval), is 138h for the European standard (220V/50Hz). For the US standard (110V/60Hz) the right value is 104h. Since the goal of the software is to set the RC oscillator frequency to 1 MHz it means obtaining 138h as the result of the count. So if the result of the count is greater than 138h, it means that the frequency is too high so the program increases the value of RCCR/SICSR registers in order to decrease the RC oscillator frequency. And if the result is less than 138h, the RCCR/SICSR register value is decreased in order to increase the RC oscillator frequency.

Figure 1. Dichotomous analysis of RCCR value



The RCCR register is set to 80h initially by the program, then the dichotomization starts by adding or subtracting 40h and after each iteration the result is divided by two, so that after 10 iterations the value of RCCR is set with an accuracy of one bit.

Figure 2. Using the timer input capture to measure the mains frequency



To measure the frequency, the software uses the Lite Timer input capture (LTIC) so that on each edge of the mains the value of the free running counter is stored as shown in Figure 2.. Then the microcontroller calculates the elapsed time between the two edges of the mains. This time is given by the following equation:

$$\mathrm{time} = \mathrm{nbover} \times \mathrm{F9h} + \mathrm{capture2} - \mathrm{capture1}$$

where nbover represents the number of counter overflows during the measurement, capture 1 and capture 2 are the values captured on the free running counter when an edge occurs on the mains and F9h is the overflow value of the free running counter.

If the RC oscillator frequency is equal to 1 MHz, the result time will be 138h for European standard (220V/50Hz) or 104h for US standard mains (110V/60Hz), so these are the reference values.

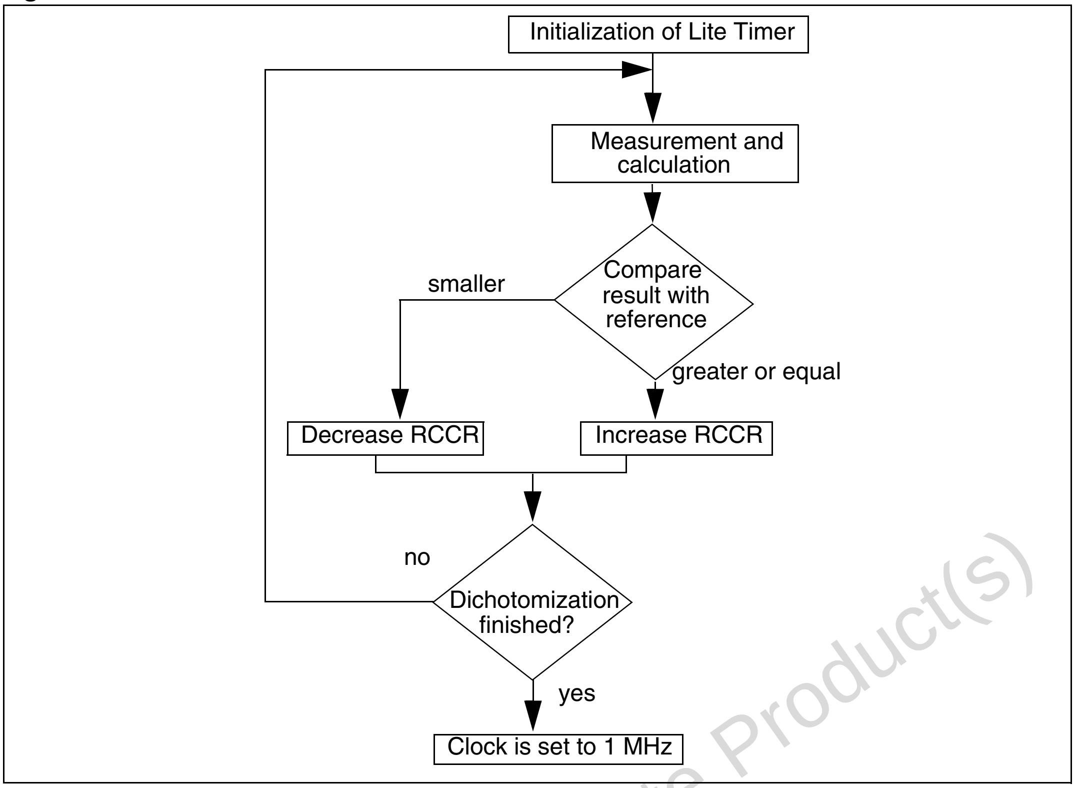
This measurement result is compared to the reference value and, depending on the result of the comparison, the microcontroller adds to or subtracts from the current RCCR/SICSR register values.

1.2 Basic version

In this version the measurement is done only once for each dichotomization step. This allows the calibration software to be light and fast. It requires only 128 bytes of program memory and 5 bytes of RAM during calibration. The calibration takes less than 200 ms to be completed.

The software works as shown in the following flowchart. The assembly code and a more detailed flowchart can be found in Section 4.

Figure 3. Basic software flowchart



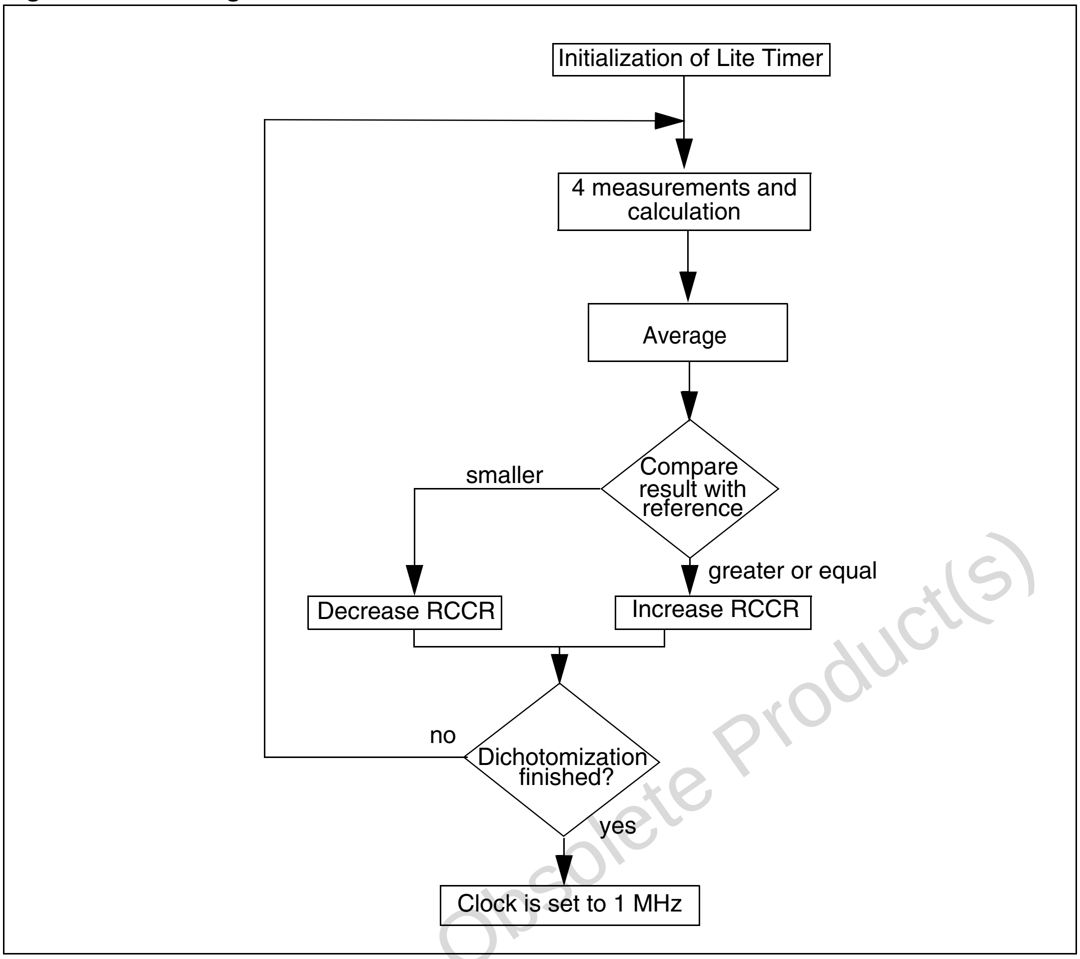
1.3 Average version

This version uses the method described in Section 1.1 except it performs four measurements and uses their average for each dichotomization step. It is useful when the mains is noisy. For instance, when a motor starts it generates a tension pick and this can be considered as a mains edge.

This version is safer than the basic one but it requires more resources. It uses 136 bytes of program memory and 11 bytes of RAM during calibration. The calibration takes less than 800 ms to be completed.

The average version works as shown in the following flowchart. The assembly code can be found in Section 4.

Figure 4. Average software flowchart



2 Power supply and timebase delivery circuit

The following figures show circuits which will provide 5V DC to the ST7ULTRALITE and protect the input capture from overcurrent. If no power supply is needed, the only component to keep is the resistor on the LTIC input, which is mainly to protect from overcurrent.

2.1 Basic circuit

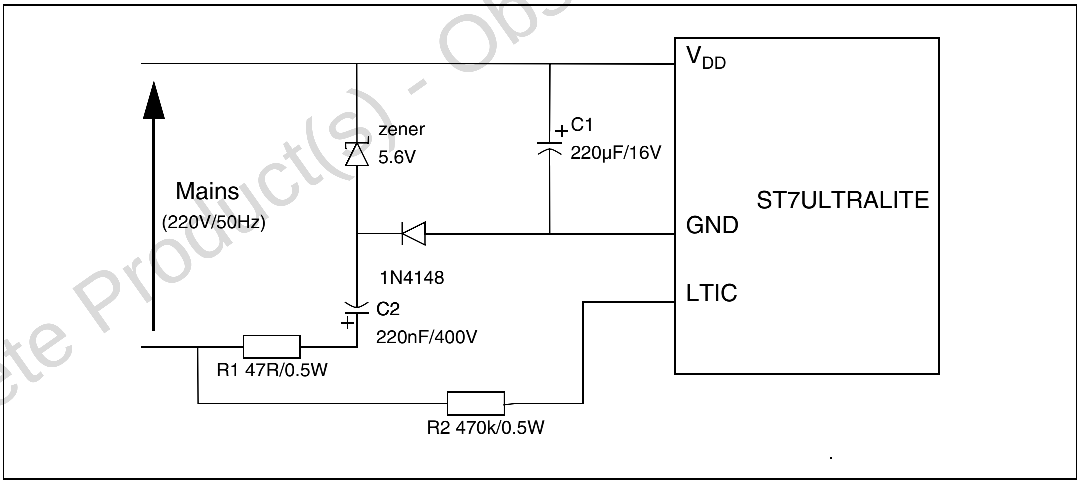
This circuit contains a capacitive power supply which converts the 220V/50Hz of the mains, as well as the 110V/60Hz of the US mains, into 5V DC.

Warning: be aware that this kind of power supply cannot be used if there are big current variations.

It also inputs 220V/50Hz to the Lite Timer Input Capture pin (LTIC/PA2) protected by resistor R2.

The incoming alternating signal on the LTIC input pin is 220V/50Hz. Because of the clamping diode on the input of the ST7ULTRALITE, the input signal can be considered as a 0-5V square signal.

Figure 5. Power supply and timebase delivery circuit diagram



The maximum current available in the microcontroller depends on the C2 value. Table 1 gives the maximum average current versus the capacitor value. The average current follows the equation below:

$$Imax = Vmax \cdot 2 \cdot f \cdot C$$

In the case above, C2 is equal to 220nF so the available current is limited to 4.9 mA in the case of a European mains. To have the same current levels in the case of the US mains

(110V/60Hz), C2 must be multiplied by two. A 440nF capacitor will limit the current to 4.9 mA.

For the US standard, R2 must be divided by two in order not to limit the current too much on the LTIC input. A 220kΩ resistor is enough in this case.

Table 1. Maximum MCU current

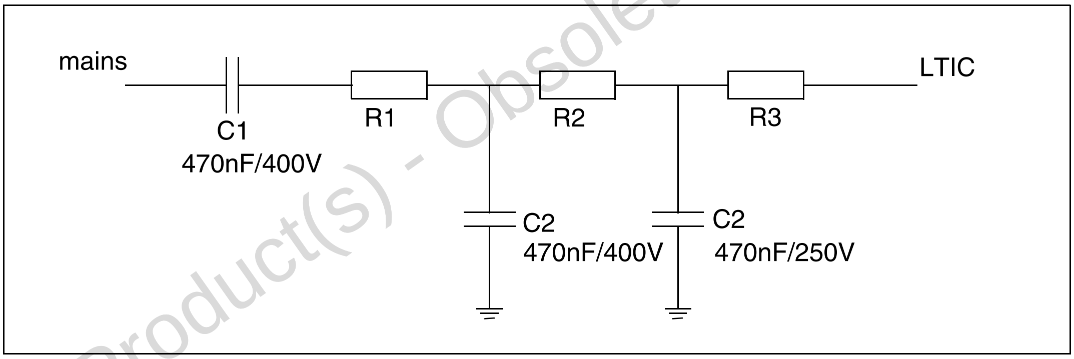
Capacitor C2	Maximum Current
220nF	4.9mA
330nF	7.3mA
470nF	10.4mA
680nF	15mA
1µF	22.1mA

2.2 Hardware protection

To prevent bad measurements due to noisy mains, a filter can be added between the mains and the input capture of the ST7ULTRALITE. The following figure shows one example of a filter. This filter is a pass band centered on the mains frequency in order to reject all frequency which could be understood by the microcontroller as a mains edge.

Please note that this is just a second order filter and that this may not be enough if the mains is really noisy. Any kind of filter can be added on the LTIC.

Figure 6. Band pass filter



The pass band filter above must be tuned to mains frequency. The value of the resistors for this filter is given in the table below.

Table 2. Resistor values

resistors	50Hz/220V	60Hz/110V
R1	6.8K/0.5W	5.6K/0.5W
R2	6.8K/0.5W	5.6K/0.5W
R3	470K/0.5W	220K/0.5W

3 Conclusion

This system allows you to have a power supply for the microcontroller and an auto adjustable clock set to 1, 2, 4 or 8MHz, selected by prescaler, with the required accuracy whatever the external conditions.

This solution also offers the advantage of being less expensive than a solution with a transformer and requires less space.

It requires a small amount of space in program memory (less than 128 bytes) in its smallest version.

4 Software examples

A zip file attached to this application note contains the complete software of this calibration method.

4.1 Single alternance

This version performs only one count between two edges and changes the value of the RCCR/SICSR registers according to this measurement. This can lead to bad tuning if there is noise on the reference signal.

4.1.1 Main program

```
;All the bytes from locations 80h to 85h are used by this software to store values or as control
registers but they can be reused safely after the clock has been set.

;dichotomy value
.value                  equ    $81          ;this byte contains the value which will be added or
subtracted to/from the RCCR last value at the end of each round
;capture values
.capture1               equ    $82
.capture2               equ    $83    ;these two bytes contain the two values of the counter captured on
the edge of the mains, they are used to calculate the time elapsed between the two edges
;number of overflows
.nbover                 equ    $84    ;this byte contains the number of counter overflows during the
measurement
;control register
.cr                     equ    $85    ;this byte is used as a control register for the measurement. Its
bits allow or not the interrupts and show which step of the count is the current one.
.strtstp                equ    1      ;this is set to start the count and reset to stop it
.lsb_RCCR               equ    7      ;this bit is set when the first capture has occurred. It allows
the overflows to be counted
;address to program in NVM (optional)
.E2ADDR                 equ $86
.RAM                    equ $88

.main

       ld A, #$63
       ld AVDTHCR, A  ; set internal clock to fRC/8 meaning 1MHz targeted


       clr SICSR    ; clear the 2 lowest significant bits located in this register

       ld              A, #$80       ;value containing the value which will be
       ld              value, A      ;add or subs to/from RCCR during the dichotomy
       ld              RCCR, A       ;RCCR is set to the middle of its range of value

       clr             cr            ;clear the byte use as control register for the count

next
  clr  nbover                 ;clear the byte containing the number of timer overflow
       ld              A, LTICR      ;clear the ICF bit

       rim                           ;interrupts enable
       bset            LTCSR, #7     ;enable input capture interrupt
       bset            cr,#strtstp   ;set the start-stop bit of cr: count can start
count
  btjt cr, #strtstp, count; wait for the end of count
       clr             LTCSR         ;lite timer interrupts disable

       srl             value         ;dichotomy value divided by 2

       ld              A,#$F9        ;these lines calculate this equation:
       ld              X,nbover      ;
       mul             X,A           ;(nbover*$F9)+ capture2 - capture1
       add             A, capture2   ;
       jrnc            nocarry       ;this equation is calculated with 16 bits
       inc             X             ;
```

```
nocarry
  sub   A, capture1            ;MSB are in register X
        jrnc          noneg         ;
        dec           X             ;and LSB in register A.

noneg
  cp    X, #$01                ;if mains frequency is 50Hz the reference value is $138
        jrmi          minus         ;if it is 60Hz the reference is $104.the program first
        jreq          compare       ;compares MSB with $01 and then compare LSB with
        jp            plus          ;$38 for 50Hz and $04 for 60Hz. if the calculated
compare cp            A, #$38       ;value is smaller than the reference the program jump to
        jrmi          minus         ;minus to decrease RCCR else it increase RCCR

plus
        btjt cr,#lsb_RCCR,plus_lsb
        ld            A, RCCR
        add           A, value      ;add value if counted value is greater than ref
        jra           new
plus_lsb
  btjt  value, #5, p_lsb0
  btjt  value, #4, end
  ld A, value
  ld SICSR, A  ;add value if counted value is greater than ref
  jra   next
p_lsb0
        bset SICSR,#5          ;add value if counted value is greater than ref
        jra next
minus
  btjt cr,#lsb_RCCR,minus_lsb
  ld    A, RCCR
        sub           A, value      ;subtract value if Y is smaller
  jra new
minus_lsb
  btjt  value,#5, m_lsb0
  btjt  value, #4, clr_lsb0
  bres RCCR,#0  ;reset the LSb of RCCRH
  ld A, value
  ld SICSR, A  ;substract value if counted value is smaller than ref
  jra   next
m_lsb0
        bres SICSR,#6
        bset SICSR,#5  ;subtract value if Y is smaller
        jra next
clr_lsb0
        bres SICSR,#5  ;reset the LSb of RCCRL
        jra end
new
        ld            RCCR,A        ;enter the new value in RCCR
        btjf          value, #0, next;stop after 7 rounds


  bset cr, #lsb_RCCR
  ld A, #$80
  ld value, A
  jra next

.end_calibration   ; end of the calibration
; at this point the Fcpu is set to 1MHz
; the last operation is to set the clock to the targeted value by setting the prescaler register
         ld A, #$03                         ; set clock to fRC meaning 8MHz
        ; ld A, #$23                        ; set prescaler to fRC/2
        ; ld A, #$43                        ; set prescaler to fRC/4
        ; ld A, #$63                        ; set prescaler to fRC/8
         ld AVDTHCR,A                       ; in the three cases AVD is set off
```

4.1.2 Input capture interrupt

```
        ld            A, LTICR              ;load captured value in A
        btjt          LTCSR, #4, finish     ;test if it is first or second capture
        bset          LTCSR, #4             ;allow timebase interrupt in order to count the number of
overflows
        ld            capture1, A           ;captured value is stored in capture1
        jp            endit1

finish  ld            capture2, A           ;if it is the second capture, captured value is stored in
capture2
        clr           cr                    ;clear cr to end the count
```

```
endit1
        iret
```

4.1.3 Timebase interrupt

```
        ld          A, LTCSR        ;clear TB bit
        inc         nbover          ;increment number of overflows
endit2
        iret
```

4.1.4 Writing in non volatile memory for products without Data EEPROM

To store the final value of RCCR/SICSR registers in non volatile memory, the following lines must be added after the timer interrupts have been disabled in the main program. As Data EEPROM is not embedded in the ST7ULTRALITE, the storage is done in program memory, so the sector 0 size must be 0.5k (selected by option byte). The programmation routine must be executed from RAM, so it is first loaded in RAM and then called. Both RCCR and SICSR registers are saved.

```
; Content of RCCR and SICSR is saved at FC00h and FC01h

; < RESET_FCSR >

 LD A,#$56 ; Enter RASS keys to unlock FCSR register
 LD FCSR,A
 LD A,#$AE
 LD FCSR,A

; < LOAD_RAM >

 LD  X,#$3F         ; Copy programming software driver 32 bytes = 4 lines
.RAM_Copy            ; into RAM from address 0083h
 LD  A,(RAM_Driver,X)
 LD  (RAM,X),A
 DEC X
 JRPL RAM_Copy

; < USER_APPLICATION_PROGRAM >

; < FIRST_PROG >

 LD  A,#$FC                   ; High address
 LD  X,A                      ;
 clr Y          ; define FC00 as destination address


 LD  {E2ADDR},X       ; Address high to be programmed (0081h) is in X
 LD  {E2ADDR+1},Y      ; Address low  to be programmed (0082h) is in Y

 CALL RAM            ; Call the programming driver located into RAM

JP USER_APPLICATION
; ---------------------------------------------------------------------------
; ROUTINE: XemulE2_ByteProg
; DESCRIPTION: Emulated data EEPROM byte programming driver routine
; BEFORE: A  = data to be programmmed
;     X:Y = address where it has to be programmed [FC00h..FDFFh]
; ---------------------------------------------------------------------------


.RAM_Driver
 BSET FCSR,#LAT        ; Enable Emul. EEPROM latches
 LD     A,FCSR
 CLR  X

 LD  A, RCCR
 LD  ([E2ADDR.w],X),A; Set address/data to be programmed
 inc  X
 LD  A, SICSR
 LD  ([E2ADDR.w],X),A; Set address/data to be programmed

 BSET FCSR,#PGM        ; Launch the Emul. EEPROM programming
```

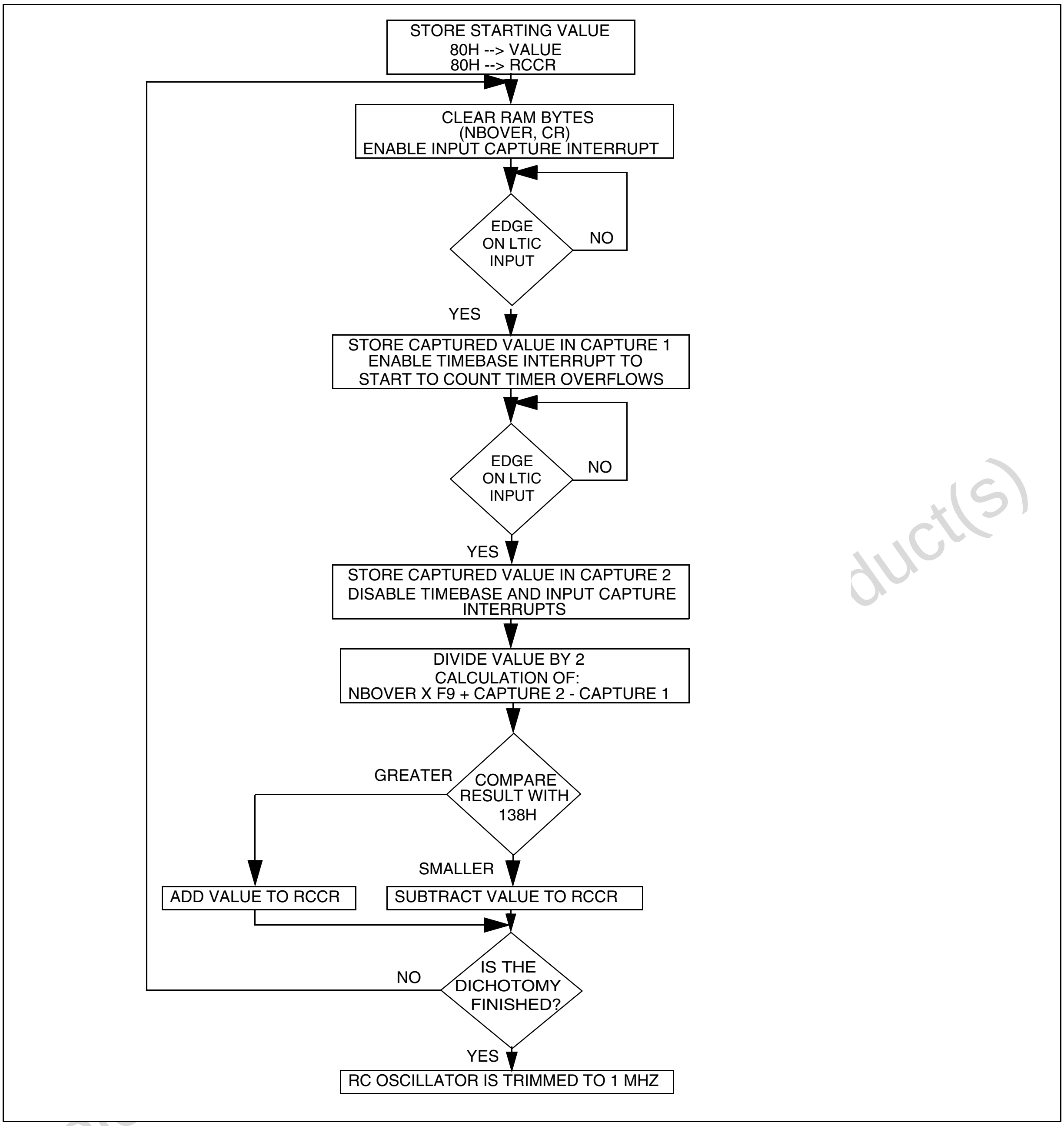
```
.EEPROM_Prog
 BTJT FCSR,#PGM,EEPROM_Prog; Wait end of programming (~5ms)
 RET
```

4.1.5 Writing in non volatile memory for products with Data EEPROM

To store final value of RCCR/SICSR registers in EEPROM, add theses lines after disabling the timer interrupts in the main program.

```
        ld          RCCR, A
        bset        EECSR,#1            ;start to enter value in the EEPROM
        ld          $1003,A             ;load value of the RCCR in EEPROM
        ld          A, SICSR
        ld          $1004,A             ;load value of the SICSR in EEPROM
        bset        EECSR,#0            ;start to write in the EEPROM
wait    btjt        EECSR,#0,wait       ;wait for the end of writing in EEPROM
```

4.1.6 Detailed basic version software flowchart



4.2 Average version

This version performs the count between two edges four times and changes the value of the RCCR/SICSR registers according to the average of these measurements. This method allows to perform a better tune of the RC oscillator especially in noisy environment.

4.2.1 Main program

```
;All the bytes from locations 80h to 8Bh are used by this software to store values or as control
registers but they can be reused safely after the clock has been set.

;dichotomy value
.value              equ    $81          ;this byte contains the value which will be added or
subtracted to/from the RCCR last value at the end of each round
;capture values
.capture1           equ    $82
.capture2           equ    $86    ;these bytes contain the values of the counter captured on the
edge of the mains, they are used to calculate the time elapsed between the two edges
;number of overflows
.nbover             equ    $8A    ;this byte contains the number of counter overflows during the
measurement
;control register
.cr                 equ    $8B    ;this byte is used as a control register for the measurement. Its
bits allow or not the interrupts and show which step of the count is the current one.
.strtstp            equ    1      ;this is set to start the count and reset to stop it
.lsb_RCCR           equ    7      ;this bit is set when the first capture has occurred. It allows
the overflows to be counted

;address to program in NVM (optional)
.E2ADDR             equ $86
.RAM                equ $88

.main

       ld A, #$63
       ld AVDTHCR, A  ; set internal clock to fRC/8 meaning 1MHz targeted

       ld            A, #$80      ;value containing the value which will be
       ld            value, A     ;add or subs to/from RCCR during the dichotomy
       ld            RCCR, A      ;RCCR is set to the middle of its range of value

       clr           cr           ;clear the byte use as control register for the count

next
  clr  nbover             ;clear the byte containing the number of timer overflow
       ld            A, LTICR     ;clear the ICF bit

       clr           Y
capture
  rim                     ;interrupts enable
       bset          LTCSR, #7    ;enable input capture interrupt
       bset          cr,#strtstp  ;set the start-stop bit of cr: count can start
count
  btjt cr, #strtstp, count; wait for the end of count
       clr           LTCSR        ;lite timer interrupts disable
       inc           Y
       cp            Y,#4         ;repeat the capture four time to make an average
       jrne          capture

       srl           value        ;dichotomy value divided by 2

       clr           Y
       ld            A,#$F9       ;these lines calculate this equation for the four
       ld            X,nbover;measures:
       mul           X,A            ;(nbover*$F9)+ capture2 - capture1
calcul
  add  A, (capture2,Y)      ;
       jrnc          nocarry      ;this equation is calculated with 16 bits
       inc           X            ;
nocarry
  sub  A, (capture1,Y) ;MSB are in register X
       jrnc          noneg        ;
       dec           X                ;and LSB in register A.
noneg  inc           Y
       cp            Y,#4
```

```
        jrne           calcul

        srl            A                 ;these lines calculate the average of the last four
        srl            X                 ;measures by dividing their total by 4. It is done by
        jrnc           carry1        ;two consecutive right shift on the 16 bit result.
        add            A,#$80
carry1
  srl   A
        srl            X
        jrnc           carry2
        add            A,#$80

carry2
  cp    X, #$01             ;if mains frequency is 50Hz the reference value is $138
        jrmi           minus  ;if it is 60Hz the reference is $104.the program first
        jreq           compare;compares MSB with $01 and then compare LSB with
        jp             plus          ;$38 for 50Hz and $04 for 60Hz. if the calculated
compare
  cp    A, #$38             ;value is smaller than the reference the program jump to
        jrmi           minus  ;minus to decrease RCCR else it increase RCCR

plus
        btjt cr,#lsb_RCCR,plus_lsb
        ld             A, RCCR
        add            A, value      ;add value if counted value is greater than ref
        jra            new
plus_lsb
  btjt  value, #5, p_lsb0
  btjt  value, #4, end
  ld A, value
  ld SICSR, A  ;add value if counted value is greater than ref
  jra   next
p_lsb0
        bset SICSR,#5          ;add value if counted value is greater than ref
        jra next
minus
  btjt cr,#lsb_RCCR,minus_lsb
  ld    A, RCCR
        sub            A, value      ;subtract value if Y is smaller
  jra new
minus_lsb
  btjt  value,#5, m_lsb0
  btjt  value, #4, clr_lsb0
  bres RCCR,#0  ;reset the LSb of RCCRH
  ld A, value
  ld SICSR, A  ;substract value if counted value is smaller than ref
  jra   next
m_lsb0
        bres SICSR,#6
        bset SICSR,#5  ;subtract value if Y is smaller
        jp next
clr_lsb0
        bres SICSR,#5  ;reset the LSb of RCCRL
        jra end

new     ld             RCCR,A        ;enter the new value in RCCR

        btjf           value, #0, next_near;stop after 7 rounds
        bset cr, #lsb_RCCR
        ld A, #$80
        ld value, A
next_near
        jp next

.end_calibration   ; end of the calibration
; at this point the Fcpu is set to 1MHz
; the last operation is to set the clock to the targeted value by setting the prescaler register
         ld A, #$03                         ; set clock to fRC meaning 8MHz
        ; ld A, #$23                        ; set prescaler to fRC/2
        ; ld A, #$43                        ; set prescaler to fRC/4
        ; ld A, #$63                        ; set prescaler to fRC/8
         ld AVDTHCR,A                       ; in the three cases AVD is set off
```

4.2.2 Input capture interrupt

```
        ld             A, LTICR           ;load captured value in A
        btjt           LTCSR, #4, finish  ;test if it is first or second capture
```

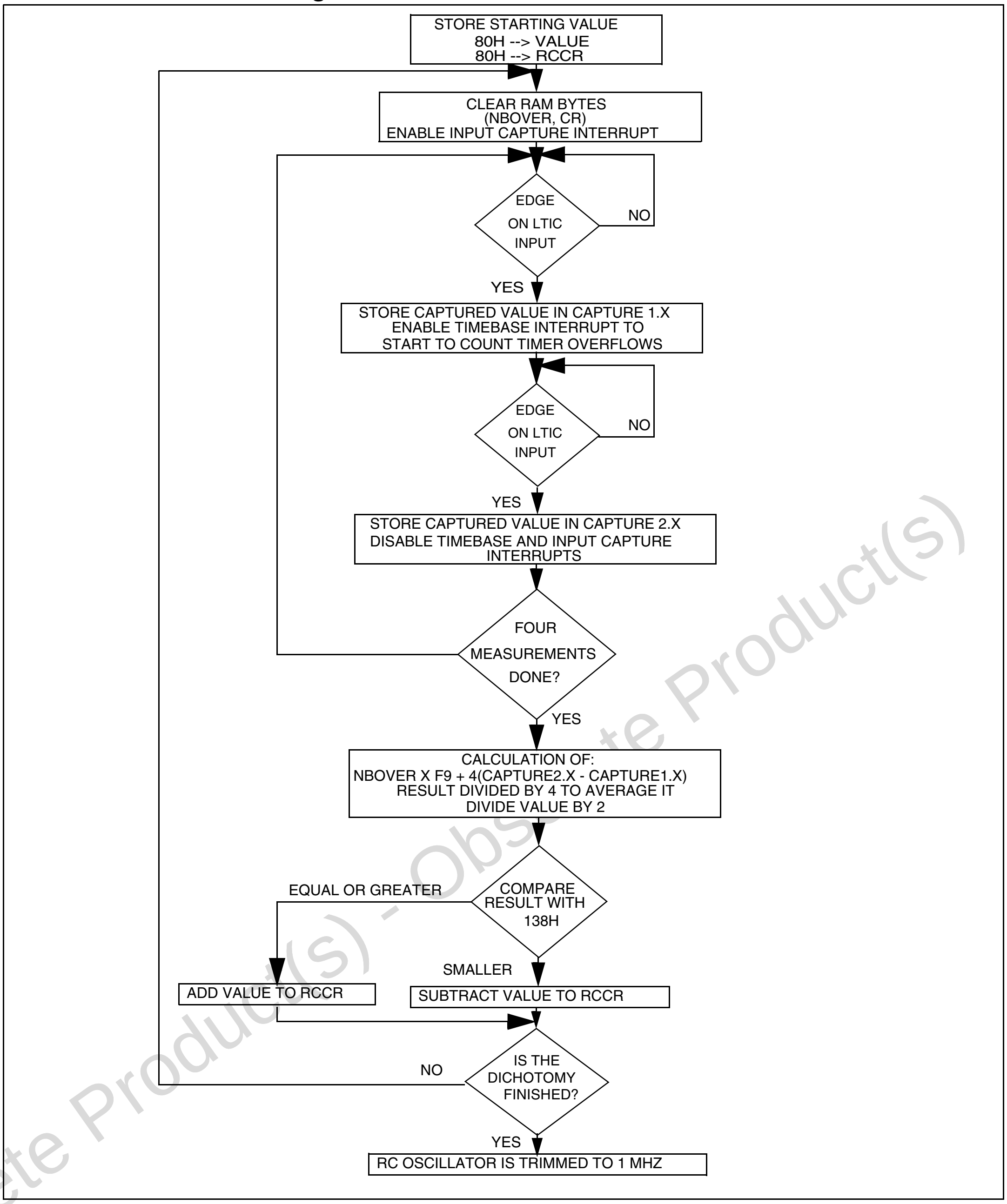
```
        bset        LTCSR, #4           ;allow timebase interrupt in order to count the number of
overflows
        ld          (capture1,Y), A     ;captured value is stored in capture1
        jp          endit1

finish
        ld          (capture2,Y), A     ;if it is the second capture, captured value is stored in
capture2
        clr         cr                  ;clear cr to end the count
endit1  iret
```

4.2.3 Timebase interrupt

```
        ld          A, LTCSR            ;clear TB bit
        inc         nbover              ;increment number of overflows
endit2
        iret
```

Table 3. Detailed average version software flowchart



5 Revision history

Table 4. Document revision history

Date	Revision	Changes
03-April-2006	1	Initial release.

Please Read Carefully: