**David Nakasone, cpe301, DA2**

Schematics:

{Fritz}

The assembly:

```
13
14  .org 0x2
15      JMP int0_isr
16
17  .def rTemp = r16          ; general purpose helper register
18  .def rInner = r17         ; counter for inner loop
19  .def rInnerTune = r18     ; tunner for inner loop
20  .def rMiddle = r19        ; counter for middle loop
21  .def rMiddleTune = r20    ; tunner for middle loop
22  .def rOuter = r21         ; counter for outer loop
23  .def rOuterTune = r22     ; tunner for outerr loop
24  .def rLED_pol = r23       ; maintains state of LED for polling
25  .def rLED_int = r24       ; maintains state of LED for interrupt
26  .def rCalls = r25         ; counter for calling delay025
27
28  .equ LOOP_INNER = 128     ; lowest loop level, iterations to execute
```

```
Output
Show output from: Build
        ---------------------------------------------------------------
        [.cseg] 0x000000 0x0000ac    172      0    172   32768   0.5%
        [.dseg] 0x000100 0x000100      0      0      0    2048   0.0%
        [.eseg] 0x000000 0x000000      0      0      0    1024   0.0%
        Assembly complete, 0 errors. 0 warnings
    Done executing task "RunAssemblerTask".
Done building target "CoreBuild" in project "AssemblerApplication2.asmproj".
Target "PostBuildEvent" skipped, due to false condition; ('$(PostBuildEvent)' != '') was evaluated as ('' !=
Target "Build" in file "C:\Program Files (x86)\Atmel\Studio\7.0\Vs\Avr.common.targets" from project "C:\User
Done building target "Build" in project "AssemblerApplication2.asmproj".
Done building project "AssemblerApplication2.asmproj".

Build succeeded.
========== Build: 1 succeeded or up-to-date, 0 failed, 0 skipped ==========
```

```
; cpe301, s22, da2, David Nakasone

; f_cpu = 16MHz, each clock period is T_cpu 0.00625 us

; inner loop runs from 0:LOOP_INNER

; middle loop runs from 0:LOOP_MIDDLE

; outer loop runs from 0:LOOP_OUTER, making a delay of 0.25 seconds

; reach any time desired with another loop that tracks calls to "delay025"

; tunning to micro-second range is possible

; no clocks allowed


.include <m328pbdef.inc>

.org 0 ; reset point

   JMP main


.org 0x2

   JMP int0_isr


.def rTemp = r16         ; general purpose helper register

.def rInner = r17        ; counter for inner loop
```

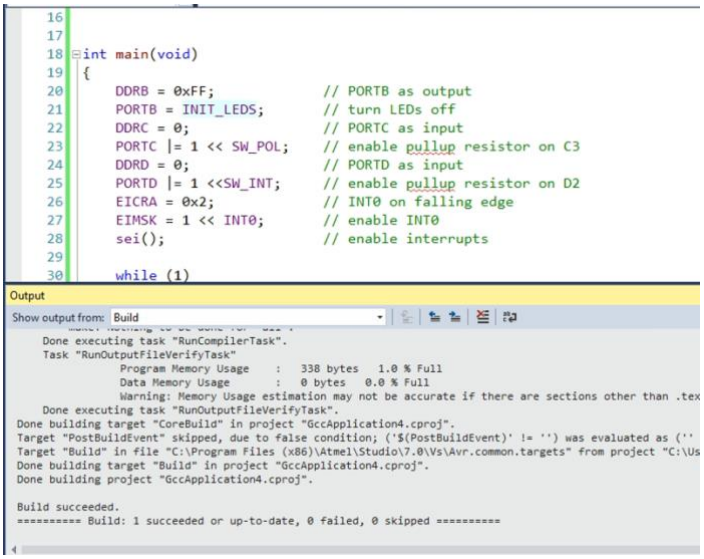
```
.def rInnerTune = r18     ; tunner for inner loop
.def rMiddle = r19        ; counter for middle loop
.def rMiddleTune = r20    ; tunner for middle loop
.def rOuter = r21         ; counter for outer loop
.def rOuterTune = r22     ; tunner for outerr loop
.def rLED_pol = r23       ; maintains state of LED for polling
.def rLED_int = r24       ; maintains state of LED for interrupt
.def rCalls = r25         ; counter for calling delay025

.equ LOOP_INNER = 128     ; lowest loop level, iterations to execute
.equ TUNE_INNER = 128     ; tuning adjustment applied to inner loop
.equ LOOP_MIDDLE = 128    ; middle loop level, iterations to execute
.equ TUNE_MIDDLE = 128    ; tunning adjustment applied to outer loop
.equ LOOP_OUTER = 34      ; top loop level, iterations to achieve 0.25 sec delay
.equ TUNE_OUTER = 160     ; tunning adjustment applied to outter loop
.equ SPINZ = 255          ; extra NOPs
.equ SW_POL = 3           ; switch for polling on PC.3
.equ LED_POL = 2          ; LED for polling on PB.2
.equ CALLS_POL = 5        ; on polling, delay025 must be called 5 times to produce 1.25 s delay
.equ SW_INT = 2           ; switch for interrupt on PD.2
.equ LED_INT = 5          ; LED for interrupt on PB.5
.equ CALLS_INT = 2        ; on interrupt, delay025 must be called 2 times to produce 0.5 s delay
.equ LED_INIT = 0x3C      ; turns off LEDs on shield, revese biased

main:
   ; initialize SP
   LDI rTemp, LOW(RAMEND)
   OUT SPL, rTemp
   LDI rTemp, HIGH(RAMEND)
   OUT SPH, rTemp

   LDI rCalls, 1        ; initialize calling to at least one 250ms delay
   SBI DDRB, LED_INT    ; portB.5 as output for interrupt LED
   SBI DDRB, LED_POL    ; portB.2 as output for polling LED
   LDI rTemp, LED_INIT
   OUT PORTB, rTemp     ; start LEDs off, reversed biased
   LDI rTemp, 0
   OUT DDRC, rTemp      ; portC as input
```

```
    OUT DDRD, rTemp      ; portD as input
    SBI PORTC, SW_POL    ; portC.3 pullup resistor enabled
    SBI PORTD, SW_INT    ; portD.2 pullup resistor enabled

    LDI rTemp, 0x2
    STS EICRA, rTemp         ; INT0 is falling edge triggered
    LDI rTemp, (1 << INT0)
    OUT EIMSK, rTemp         ; enable INTO
    SEI                      ; enable interrupts


main_loop:
    IN rTemp, PINC       ; get value of PINC, using polling
    SBIS PINC, SW_POL    ; (button pushed) ? start delay : keep polling
    RCALL poll_hit       ; starts 1.25 second delay by calling delay025 x 5
    SBI PORTB, LED_POL   ; ensure LED is not bouncing
    RJMP main_loop       ; poll again


poll_hit:
    LDI rCalls, CALLS_POL    ; prepare # of calls to delay025
    CBI PORTB, LED_POL       ; turn LED on
    RCALL call_delay025      ; wait 1.25 seconds
    SBI PORTB, LED_POL       ; turn LED off
    RET                      ; returning for more polling



call_delay025:
    RCALL delay025       ; make one 250ms delay
    DEC rCalls
    BRNE call_delay025   ; (calls complete) ? returning : keep calling
    LDI rCalls, 1        ; initialize rCalls
    RET                  ; control to caller
delay025:
    LDI rInner, LOOP_INNER          ; initialize inner loop
    LDI rInnerTune, TUNE_INNER      ; initialize tuning parameter for inner loop
    LDI rMiddle, LOOP_MIDDLE        ; initialize middle loop
    LDI rMiddleTune, TUNE_MIDDLE    ; initialize tuning parameter for middle loop
    LDI rOuter, LOOP_OUTER          ; initialize outer loop
```

```
    LDI rOuterTune, TUNE_OUTER      ; initialize tuning parameter for outer loop
    LDI rTemp, SPINZ                ; initialize single NOPs
outer_loop:
    RCALL outer_loop_tune    ; apply NOPs specified by TUNE_OUTER
    RCALL middle_loop        ; iterate exterior loop C through A and B
    DEC rOuter
    BRNE outer_loop          ; (LOOP_OUTER repititions complete) ? sub-routine complete : goto outter_loop
    RCALL spin_isolated      ; execute single NOPs
    RET                      ; returning out of this sub-routine
outer_loop_tune:
    NOP                      ; kill a cycle
    DEC rOuterTune
    BRNE outer_loop_tune         ; (TUNE_OUTER time cycles executed) ? spins complete : keep spinning
    LDI rOuterTune, TUNE_OUTER    ; reset
    RET                      ; returns to outter_loop after spins are complete
middle_loop:
    RCALL middle_loop_tune      ; apply NOPs specified by TUNE_MIDDLE
    RCALL inner_loop            ; complete one iteration of interior loop
    DEC rMiddle
    BRNE middle_loop            ; (LOOP_MIDDLE repetitions occured) ? break : goto middle_loop
    LDI rMiddle, LOOP_MIDDLE    ; reset
    RET                      ; returning to loopC
middle_loop_tune:
    NOP                      ; kill a cycle
    DEC rMiddleTune
    BRNE middle_loop_tune          ; (TUNE_MIDDLE time cycles executed) ? spins complete : keep spinning
    LDI rMiddleTune, TUNE_MIDDLE    ; reset
    RET                      ; returns to middle_loop after spins are complete
inner_loop:
    DEC rInner
    BRNE inner_loop          ; (LOOP_INNER repititions occured) ? break : goto inner_loop
    LDI rInner, LOOP_INNER    ; reset
    RET                      ; returning to loopB
inner_loop_tune:
    NOP                      ; kill a cycle
    DEC rInnerTune
    BRNE inner_loop_tune         ; (TUNE_INNER time cycles executed) ? spins complete : keep spinning
    LDI rInnerTune, TUNE_INNER    ; reset
```

```
    RET                     ; returns to inner_loop after spins are complete
spin_isolated:
    DEC rTemp
    BRNE spin_isolated      ; (SPINZ single cycles) ? task complete : NOP more
    RET


int0_isr:
    LDI rCalls, CALLS_INT   ; prepare # of calls to delay025
    CBI PORTB, LED_INT      ; turn LED on
    RCALL call_delay025     ; wait 0.5 seconds
    SBI PORTB, LED_INT      ; turn LED off
    RETI


program_complete:
    RJMP program_complete   ; catch


;;;;~~~~END>  main.asm
```

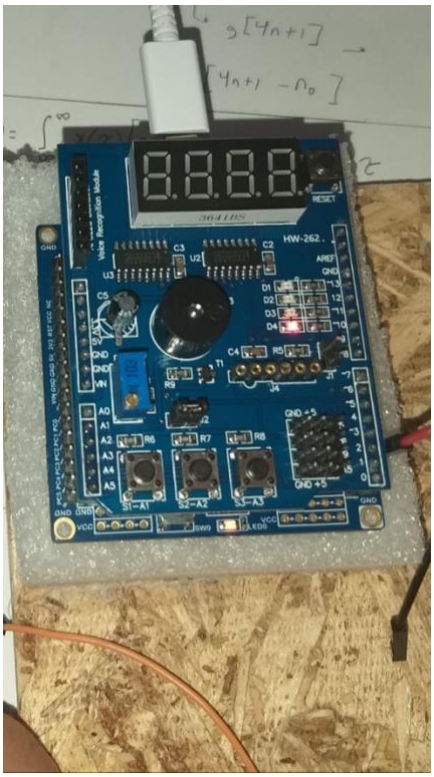
The C code:



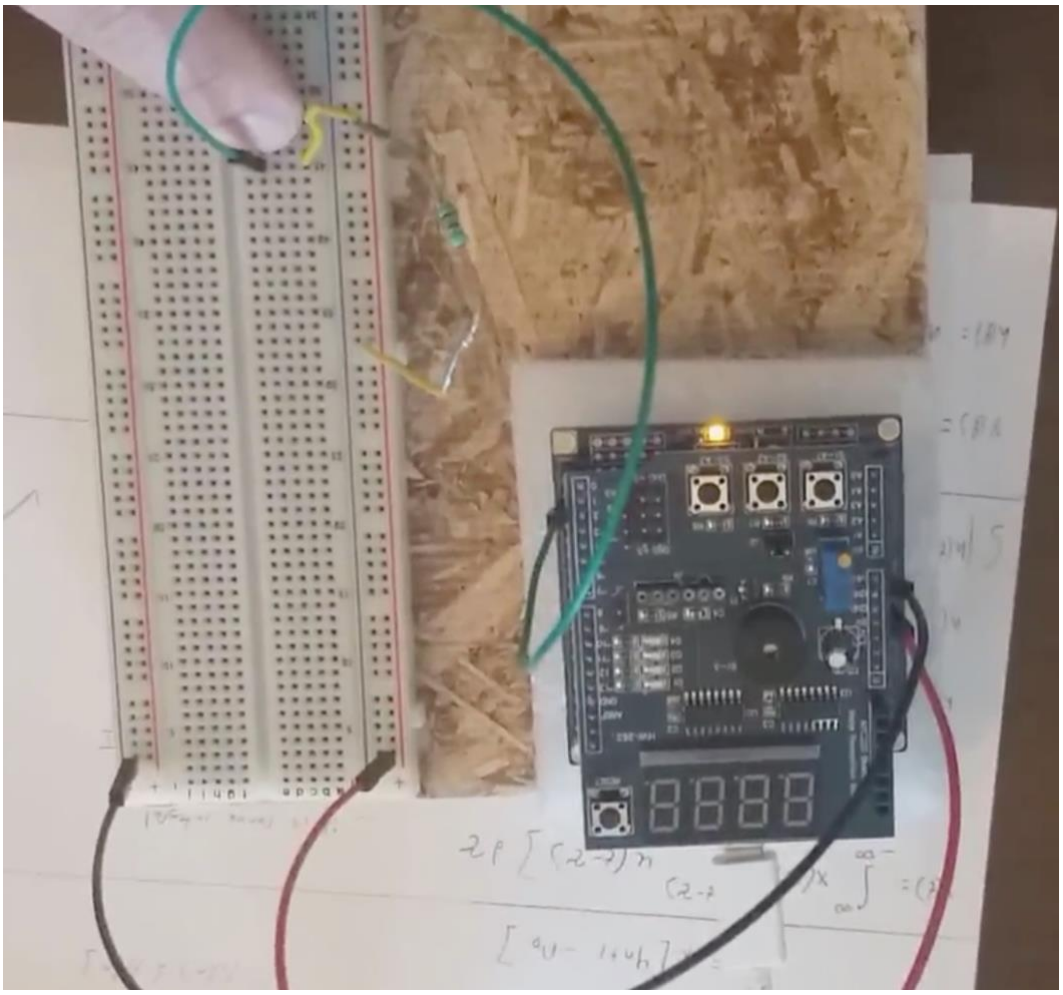
```c
/*
   cpe301, da2, all tasks
 */

#define F_CPU 16000000UL    // 16 MHz for 328pb

#include <avr/interrupt.h>
#include <avr/io.h>
#include <util/delay.h>

#define SW_POL 3          // switch on C2 triggers poll
#define SW_INT 2          // switch on D2 triggers interrupt
#define LED_POL 2         // LED on B2 indicates poll detected
#define LED_INT 5         // LED on B5 indicates interrupt detected
#define INIT_LEDS 0x3C    // turns reversed biased LEDs on shield off


int main(void)
{
   DDRB = 0xFF;            // PORTB as output
   PORTB = INIT_LEDS;      // turn LEDs off
   DDRC = 0;               // PORTC as input
   PORTC |= 1 << SW_POL;   // enable pullup resistor on C3
   DDRD = 0;               // PORTD as input
   PORTD |= 1 <<SW_INT;    // enable pullup resistor on D2
   EICRA = 0x2;            // INT0 on falling edge
   EIMSK = 1 << INT0;      // enable INT0
   sei();                  // enable interrupts

   while (1)
   {

      if (!(PINC & 0x4)) // if C3 was pressed, poll triggered
      {
         PORTB &= ~(1 << LED_POL);   // turn on B2 LED
         _delay_ms(250*5);           // wait 1.25 seconds
         PORTB = INIT_LEDS;          // turn all the LEDS off
```

```
      }
   }
}


////~~~~


ISR (INT0_vect)    // isr for external interrupt 0
{
   PORTB &= ~(1 << LED_INT);    // turn on B5 LED
   _delay_ms(250*2);            // wait 0.5 seconds
   PORTB = INIT_LEDS;           // turn all the LEDS off
}


////////~~~~~~~END>  main.c
```

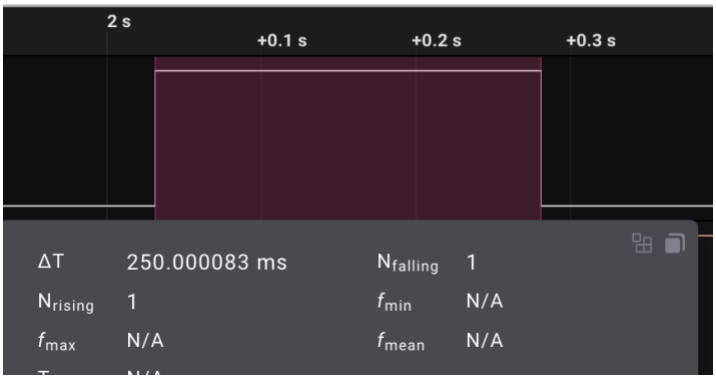
The circuit using polling (push-button):



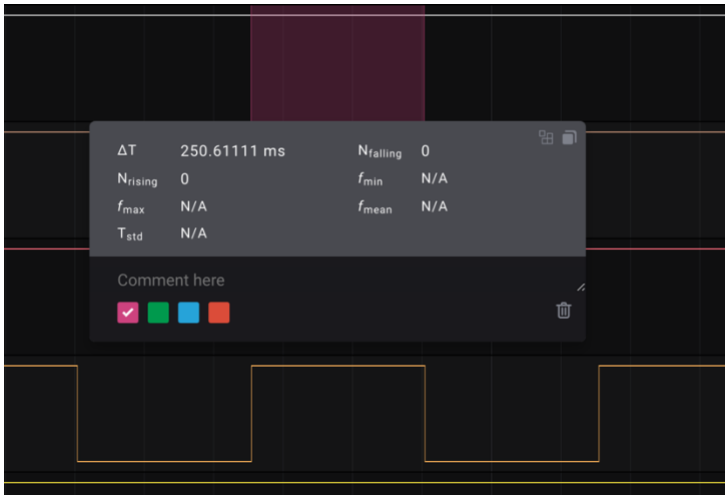
The circuit using interrupt, detected by changing connection:



The 250 ms delay determines the 1.25 and 0.5 second delays.
It was adjusted using assembly:




Using C, the delay is much easier to implement, but both are accurate:




The assembly delay ended up being more accurate than the C delay.

Video links

task1, 250 ms delay:
https://youtu.be/0c75GUvmLo0

task2, LED activated by polling:
https://youtu.be/q-BGHsYzP0Q

task3, LED activated by interrupt:
https://youtu.be/cC0MpXEx9PQ

task4, logic analyzer and timing:
https://youtu.be/vdnolojUFSs