January 18, 2015 at 22:31

**1. Introduction.** This is the firmware portion of an Ancillary Service Electric Detector or ASED.

With my emergency generator connected through an interlocked load-center, it's hard to tell when the *Ancillary Service* has been restored. The neighbor's lights offer a clue at night, but aren't reliable. Switching back to Main, from the genny, requires shutting everything off for a moment. It would be good to know if main, or Ancillary Service, is live before switching back to it.

The obvious method is to measure the voltage at the main-breaker's input, using a meter. One safety concern is that it's not breaker-protected making for a massive fault-current, should insulation be breached or the circuit shorted. Also, installation of a simple meter is somewhat involved, having to tap into live lines and, ideally, providing some form of isolation.

The obvious solution is to have a high-impedance connection very near to the source. A small capacitance could do, with a high impedance device.. Simple capacitive coupling can be had with a "gimmick"; a technique used since the 1920s. This may be several turns of THHN around the large-gage insulated incoming line. Since the voltage is with respect to neutral, and neutral is bonded to ground, just the one wire is needed to get a "sample". No need to mess with live conductors, just coupling to the electric field through the insulation already present. Installation still has some risk, but much less.

This is still now Double insulated, so whatever gizmo is connected should provide an additional level of protection, but it's better than a copper connection. Another layer of insulation could be had with a film capacitor. A Y2 film capacitor with 100 or 200 pf could be used.

With access to this signal, a circuit can be built to detect the difference between having AC and not having AC. The indication provided to the generator-operator could be a lamp or buzzer.

Looking at some numbers, the line-voltage is ± 170 V peak, with respect to ground. The peaks will be about 8.3 ms apart, in North America. The signal we will see will be much less, depending on the circuit's input impedance and capacitance, but should be good..

The circuit would need a high input impedance, so as to see a strong enough signal. The circuit would need a reference to ground to compare to. The input may need a bit of protection from line transients, which could pass trough the gimmick.

I had seven Adafruit Industry Trinkets just laying around. They use the Atmel ATTINY85 processor. The analog inputs are about 100 MΩ. Not great, but I think it should be good enough. If we can muster 1 pf of gimmick, we will have $\frac{1}{2\pi f_c}$ of $X_c$. Ohms law indicates $100 \times 10^6(\frac{170}{X_c+100\times10^6}) = 6.16$ volts peak, ignoring input pin capacitance. The steering diodes will keep the analog innards safe since the current is so low. Supply voltage at "BAT" is 5.5 to 16 V and it has a red LED on-board.

**2. Implementation and Specification.** In use, the AC signal goes to the pin marked #2 on the Trinket, PB2 on the chip, and in the Atmel datasheet. The LED port is marked #1, which is PB1. This pin goes positive to turn the LED on. The Siren port is marked #0, and is PB0. This pin goes positive to turn the siren on. The "Clear" input is on #3, PB3 on the chip. This pin should be pushed to the 5V return (supply negative) to clear the siren.

The LED will light immediately whenever AC is detected. It will turn off when the "no wave" timer times out. If armed, the siren will start when `"WAVETHRESHOLD"` count of sinewaves are detected. The siren is armed when the nowave timer expires `"ARMTHRESHOLD"` times. The siren is stopped and disarmed with either the "clear" button or power-cycle.

Extensive use was made of the datasheet, Atmel "Atmel ATtiny25, ATtiny45, ATtiny85 Datasheet" Rev. 2586QAVR08/2013 (Tue 06 Aug 2013 03:19:12 PM EDT).

⟨ Include 5 ⟩
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**3.** `"F_CPU"` is used to convey the Trinket clock rate.

```
#define F_CPU 8000000UL
```

**4.** Here are some Boolean definitions that are used.

```
#define ON 1
#define OFF 0
#define SET 1
#define CLEAR 0
```

**5.** ⟨ Include 5 ⟩ ≡

```
#include <avr/io.h>      /* need some port access */
#include <util/delay.h>      /* need to delay */
#include <avr/interrupt.h>      /* have need of an interrupt */
#include <avr/sleep.h>      /* have need of sleep */
#include <stdlib.h>
#include <stdint.h>
```

This code is used in section 2.

**6.** Here is a structure to keep track of the state of things.

⟨ Types 6 ⟩ ≡

```
typedef struct {
  uint8_t wavelesswait;      /* delay to remain as if waveless, to ensure waves */
  uint16_t armwait;      /* countdown index to arm siren */
  uint8_t armed;      /* non-zero indicates that the siren is armed */
  const uint8_t nowavecount;      /* time until siren arm */
} statestruct;
```

This code is used in section 2.

**7.** ⟨ Prototypes 7 ⟩ ≡

```
void ledcntl(uint8_t state);      /* LED ON and LED OFF */
void sirencntl(uint8_t state);    /* alarm siren control */
void chirp(uint8_t state);        /* alarm siren modulation */
void waveaction(statestruct *);   /* what is done when a wave is detected */
void nowaveaction(statestruct *); /* what is done if waves don't come */
void clear(statestruct *);        /* what is done if clear is pressed */
```

This code is used in section 2.

**8.** My lone global variable is a function pointer. This lets me pass arguments to the actual interrupt handlers. This pointer gets the appropriate function attached by one of the `"ISR()"` functions.

⟨ Global variables 8 ⟩ ≡

```
void(*handleirq)(statestruct *) = Λ;
```

This code is used in section 2.

**9.** Here is *main*( ).

```
int main(void){
```

**10.** `"NOWAVETIME"` is the time allowed by the nowave timer to be waveless before arming the siren.

```
#define NOWAVETIME 500U   /* preset ms for the timer counter. This is close to maximum */
```

**11.** The prescaler is set to clk/16484 by ⟨ Initialize the no-wave timer 34 ⟩. `"nowavecount"` is the timer preset so that overflow of the 8-bit counter happens in about 500 ms. With `"F_CPU"` at 8 MHz, the math goes: $\lfloor \frac{0.5 seconds \times (8 \times 10^6}{16384} \rfloor = 244$. Then, the remainder is $256 - 244 = 12$, thus leaving 244 counts or about 500 ms until time-out, unless it's reset.

Since `"nowavecount"` is a constant, it must be initialized when declared.

```
statestruct s_state = { . nowavecount = (uint8_t)(256 - (NOWAVETIME/1000U) * (F_CPU/16384U)) } ;
```

**12.** Device pins default as simple inputs so the first thing is to configure to use LED and Siren pins as outputs. Additionally, we need the clear button to wake the device through an interrupt.

⟨ Initialize pin outputs and inputs 30 ⟩

**13.** The LED is set, meaning 'on', assuming that there is an AC signal. The thought is that it's better to say that there is AC, when there isn't, as opposed to the converse.

```
ledcntl(ON);
```

**14.** Here the timer is setup.

⟨ Initialize the no-wave timer 34 ⟩

**15.** The Trinket runs at relatively speedy 8 MHz so the slow 60 Hz signal is no issue. One could use the ADC but that doesn't make too much sense as the input may spend a lot of time clipped. We just need to know when the signal changes. The inbuilt comparator seems like the right choice, for now.

⟨ Initialize the wave detection 35 ⟩

**16.** Of course, any interrupt function requires that bit "Global Interrupt Enable" is set; usually done through calling sei().

```
sei( );
```

**17.** Rather than burning loops, waiting for something to happen for 16 ms, the "sleep" mode is used. The specific type of sleep is 'idle'. In idle, execution stops but timers continue. Interrupts are used to wake it.

⟨ Configure to wake upon interrupt 36 ⟩

**18.** Alarm arm delay in "nowave" counts of whose size is defined by time `"NOWAVETIME"`.

```
#define ARMTHRESHOLD 1200U    /* Range to 65535 */
  s_state.armwait = ARMTHRESHOLD;
```

**19.** `"WAVETHRESHOLD"` is the number of waves, that AC must be present to consider it 'ON'. 15 counts, or waves; about 250 ms at 60 Hz. Range is 0 to 255 but don't take too long or the nowave timer will will overflow. Keep in mind that neither clock nor genny frequency is perfect.

```
#define WAVETHRESHOLD 15U    /* range maybe to 20, with a 500 ms nowave time */
  s_state.wavelesswait = WAVETHRESHOLD;
```

**20.** This is the loop that does the work. It should spend most of its time in *sleep_mode*, comming out at each interrupt event.

```
for ( ; ; )    /* forever */
{
```

**21.** Now we wait in "idle" for any interrupt event.

```
  sleep_mode( );
```

**22.** If execution arrives here, some interrupt has been detected. It could be that a sinewave was detected. It could be that the NOWAVES timer overflowed, since there have been no sinewaves for an extended period. It could be that the siren was so annoying that the operator pressed the "Clear" button. Regardless, the respective ISR will have assigned *handleirq*( ) to the handling funtion.

```
  if (handleirq ≠ Λ)    /* not sure why it would be, but to be safe */
  {
    handleirq(&s_state);    /* process the irq through it's function */
    ⟨ Hold-off all interrupts 37 ⟩handleirq = Λ;    /* reset so that the action cannot be repeated */
  }    /* end if handleirq */
}    /* end for */
  return 0;    /* it's the right thing to do! */
}    /* end main() */
```

**23. Interrupt Handling.** If a wave is detected, it's counted. Once the counter reaches zero, the light and, if armed, the siren are activated. Also, the timer for nowave is reset; after all, there is a wave.

If the nowave timer overflows, almost the opposite happens. The LED and siren are turned off. The waveless counter is reset. After some passes, the siren will be armed. Finally, the flag is reset, as before.

*waveaction*( ) function is called every time there is a wave detected.

```
void waveaction(statestruct *s_now)
{
  s_now→wavelesswait = (s_now→wavelesswait) ? s_now→wavelesswait − 1 : 0;      /* countdown to 0 */
    /* ledcntl(ON); */
  if (¬s_now→wavelesswait)      /* ancillary electric service restored */
  {
    ledcntl(ON);
    if (¬s_now→armed) chirp(ON);      /* annunciate */
    s_now→armwait = ARMTHRESHOLD;      /* reset the arm counter */
    TCNT1 = s_now→nowavecount;      /* reset the nowave timer */
  }     /* end if wavelesswait */
}
```

**24.**

*nowaveaction*( ) is called when waves have been absent long enough for the timer to expire.

```
void nowaveaction(statestruct *s_now)
{
  ledcntl(OFF);
  chirp(OFF);      /* ASE dropped, stop alarm chirp */
  s_now→wavelesswait = WAVETHRESHOLD;      /* waveless again */
  s_now→armwait = (s_now→armwait) ? s_now→armwait − 1 : 0;      /* countdown to 0, but not lower */
  if (¬s_now→armwait) (s_now→armed = SET);
}
```

**25.**

*clear*( ) is called whenever the operator presses the clear button.

```
void clear(statestruct *s_now)
{
  s_now→armwait = ARMTHRESHOLD;
  s_now→armed = CLEAR;
}
```

**26.** The ISRs are pretty skimpy as they are only used to point *handleirq*( ) to the correct function. The need for global variables is minimized.

This is the vector for the main timer. When this overflows it generally means the ASE has been off for as long as it took TCINT1 to overflow from it's start at NOWAVETIME.

```
    /* Timer ISR */
ISR(TIMER1_OVF_vect)
{
  handleirq = &nowaveaction;
}
```

**27.** This vector responds to all falling comparator events resulting from ac AC signal at the MUX input. It's expected to fire at line frequency.

```
    /* Comparator ISR */
ISR(ANA_COMP_vect)
{
  handleirq = &waveaction;
}
```

**28.** This vector responds to the 'Clear' button at pin #3 or PB3.

```
    /* Clear Button ISR */
ISR(PCINT0_vect)
{
  handleirq = Λ;
}
```

**29. These are the supporting routines, procedures and configuration blocks.**
Here is the block that sets-up the digital I/O pins.

**30.** ⟨ Initialize pin outputs and inputs 30 ⟩ ≡

```
{   /* set the led port direction; This is pin #1 */
  DDRB |= (1 ≪ DDB1);    /* set the siren port direction */
  DDRB |= (1 ≪ DDB0);    /* enable pin change interrupt for clear-button */
  PCMSK |= (1 ≪ PCINT3);    /* General interrupt Mask register for clear-button */
  GIMSK |= (1 ≪ PCIE);
}
```

This code is used in section 12.

**31.** Siren function will arm after a 10 minute power-loss; that is, the Trinket is running for about 10 minutes without seeing AC at pin #2. Once armed, siren will chirp for 100 ms at a 5 second interval, only while AC is present. In fact it is called with each AC cycle interrupt so that `CHIRPLENGTH` and `CHIRPPERIOD` are defined a multiples of $\frac{1}{Hz}$. It may be disarmed, stopping the chirp, by pressing the "clear" button or a power-cycle.

Chirp parameters for alarm. These unit are of period $\frac{1}{f}$ or about 16.6 ms at 60 Hz.

```
#define CHIRPLENGTH 7    /* number of waves long */
#define CHIRPPERIOD 200    /* number of waves long */
  void chirp(uint8_t state)
  {
    static uint8_t count = CHIRPLENGTH;
    count = (count) ? count − 1 : CHIRPPERIOD;
    sirencntl((count > CHIRPLENGTH ∨ state ≡ OFF) ? OFF : ON);
  }
```

**32.**
Here is a simple function to flip the LED on or off.

```
  void ledcntl(uint8_t state)
  {
    PORTB = state ? PORTB | (1 ≪ PORTB1) : PORTB & ∼(1 ≪ PORTB1);
  }
```

**33.** And the same for the siren.

```
  void sirencntl(uint8_t state)
  {
    PORTB = state ? PORTB | (1 ≪ PORTB0) : PORTB & ∼(1 ≪ PORTB0);
  }
```

**34.** A timer is needed to to encompass some number of waves so it can clearly discern off from on. For this "nowave" function we use Timer 1. The timer can trigger an interrupt upon overflow. This is done by setting `TIMSK`. It could overflow within about $\frac{1}{2}$ second. Over the course of that time, 25 to 30 comparator interrupts are expected. When the timer interrupt does occur, the LED is switched off.

Comparator Interrupts are counted and at `WAVETHRESHOLD` this timer is reset and the LED is switched back on.

A very long prescale of 16384 counts is set by setting certain bits in `TCCR1`.

⟨ Initialize the no-wave timer 34 ⟩ ≡

```
{
  TCCR1 = ((1 ≪ CS10) | (1 ≪ CS11) | (1 ≪ CS12) | (1 ≪ CS13));      /* Prescale */
  TIMSK |= (1 ≪ TOIE1);      /* Timer 1 f_overflow interrupt enable */
}
```

This code is cited in section 11.

This code is used in section 14.

**35.** The ideal input AN1 (PB1), is connected to the LED in the Trinket! That's not a big issue since the ADC's MUX may be used. That MUX may address PB2, PB3, PB4 or PB5. Of those, PB2, PB3 and PB4 are available. Since PB3 and PB4 are use for USB, PB2 makes sense here. This is marked #2 on the Trinket.

PB2 connects the the MUX's ADC1. Use of the MUX is selected by setting bit ACME of port ADCSRB. ADC1 is set by setting bit MUX0 of register ADMUX

Disable digital input buffers at AIN[1:0] to save power. This is done by setting AIN1D and AIN0D in register DIDR0.

Both comparator inputs have pins but AIN0 can be connected to a reference of 1.1 VDC, leaving the negative input to the signal. The ref is selected by setting bit ACBG of register ACSR.

The interrupt can be configured to trigger on rising, falling or toggle (default) by clearing/setting bits ACIS[1:0] also on register ACSR. There is no need for toggle, and so falling is selected by simply setting ACIS1.

To enable this interrupt, set the ACIE bit of register ACSR.

⟨ Initialize the wave detection 35 ⟩ ≡

```
{
  ADCSRB |= (1 ≪ ACME);      /*enable the MUX input ADC1/PB2/pin #2 */
  ADMUX |= (1 ≪ MUX0);      /*set bit MUX0 of register ADMUX */
  DIDR0 |= ((1 ≪ AIN1D) | (1 ≪ AIN0D));      /* Disable digital inputs */
  ACSR |= (1 ≪ ACBG);      /*Connect the + input to the band-gap reference */
  ACSR |= (1 ≪ ACIS1);      /* Trigger on falling edge only */
  ACSR |= (1 ≪ ACIE);      /* Enable the analog comparator interrupt */ */
}
```

This code is used in section 15.

**36.** Setting these bits configure sleep_mode() to go to "idle". Idle allows the counters and comparator to continue during sleep.

⟨ Configure to wake upon interrupt 36 ⟩ ≡

```
{
  MCUCR &= ∼(1 ≪ SM1);
  MCUCR &= ∼(1 ≪ SM0);
}
```

This code is used in section 17.

**37.** This is the hold-off time in $\mu$s for wave detection. This value is used by the `"_delay_us()"` function here ⟨ Hold-off all interrupts 37 ⟩.

```
#define WAVEHOLDOFFTIME 100 /* Range to 255 */
```

⟨ Hold-off all interrupts 37 ⟩ ≡

```
{ /* Disable the analog comparator interrupt */
  ACSR &= ~(1 << ACIE);
  _delay_us(WAVEHOLDOFFTIME); /* Enable the analog comparator interrupt */
  ACSR |= (1 << ACIE);
}
```

This code is cited in section 37.

This code is used in section 22.

⟨ Configure to wake upon interrupt 36 ⟩ Used in section 17.
⟨ Global variables 8 ⟩ Used in section 2.
⟨ Hold-off all interrupts 37 ⟩ Cited in section 37. Used in section 22.
⟨ Include 5 ⟩ Used in section 2.
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