Multitasking Scriptable Autotuning PID Platform

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1 Hardware

1.1 Definitons

The entirety of all physical components, resulting from this project, will be called 'device' throughout the paper.

1.2 Goals

The device is intended as a learning project for the student, but also as a open software, open-hardwre project, which anyone can create and use. Thus, the following hardware design priorities have been identified, in order of decreasing importance:

- safety - the device shall not pose a fire or electric shock hazard to the end user
- reconstructability - the device shall be composed **only** of worldwide accessible components
- longivity - the device shall remain operational for 5 years of uninterrupted service with 95% confidence
- price - the BOM for the complete device shall not exceed 100BGN
- extendability - the number of input sensors and the number of output controllers, shall be trivially configurable
- ease of assembly - it shall be possible for a person with zero hardware experience to manufacture the device
- simplicity - each component shall fufill a specific purpose, and the number of components shall be the lowest possible

1.3 Layout

Due to the requirement of extendability, the device shall consist of a number of printed circuit boards, in contrast to a single monoliotic PCB. Each PCB shall fufill a sole purpose, and any number of different modules shall be able to mate together. The following distinct roles have been identified:

- high-voltage input stage - called zero-cross detector or ZCD board from now on
- low-voltage input stage - called temperature sensor or thermometer from now on

- computational stage - called main board from now on
- high-voltage output stage - called software controlled rectifier board or SCR board from now on

The resulting design exhibits the following characteristics.

Only a single ZCD board is required, because mains waveform is invariant across the device in it's entirety. Only a single main board is required, as the selected microcontroller, although inexpensive, provides plenty of resources for numerous control loops.

In order to satisfy the requirement for simplicity, the main board is configured for a single SCR output board. However, soldering aditional connectors to the main PCB is trivial, thus acheaving extensability. The SCR output board is long-life and supports loads of up to 1kW.

The most flexible part of the system is the thermometer configuration. Due to the selected temperature sensing IC, virtually unlimited (technically up to 2^{56}) devices are supported **without any hardware changes**.

1.4 ZCD board

The ZCD board is a sensory input to the microcontroller.

Because the voltage of mains power is alternating, it is impossible to output precise amounts of power without knowing the phase of the waveform. The implementation of the ZCD board is straightforward and extremely simplified. In fact, an extensive internet search has demonstrated no other PCB has ever been designed with such a level of simplicity. In other words, **the designed PCB contains fewer elements than any known PCB for the same purpose**! This produces problems, which have deterred other designers. However, all artifats have been dealt with in software.

1.4.1 Schematic

Please refer to appendix A1 for the schematic and layout of the board.

1.4.2 Calculation

In order to protect the main board (and thus the user) from dangerous voltages, galvanic isolation is required. The standard means to this end are transformers and optocouplers. Optocouplers posess numerous advantages over transformers for our application:

– compactness

– low price

– neglegable phase shift

Furthermore, among optocouplers, the variation is considerable. We select a component with anti-parallel input LEDs, specifically designed for zero crossing - SFH620A-3. This is the most sensitive version of the IC (highest CTR), as input power is our greates concern.

Striving for minimal component count and price, the standard solution with a 10W input power resistor is dismissed. Thus, we need to work with 1/4W, E24 resistors. Due to the optocoupler's acceptable CTR, and extensive signal conditioning in software, this solution will provide to be viable!

It is worthy to note that the resistor rated voltage is of utmost importance. Because our resistors are rated to 200V peak, it would be a dangerous mistake to use a signel resistor. Therefore, the $V_{AC} = 230$V, $V_{peak} - V_{AC} * \sqrt{(2)} = 325$volt is safely spread onto two identical resistors.

Let's suppose the line voltage varies from $V_{min} = 200VAC$ to $V_{max} = 250VAC$ rms.

$$P_{inputresistors} = \frac{V_{max}^2}{R_1 + R_2}$$

$$R_1 + R_2 \geq \frac{V_{max}^2}{P_{inputresistors,max}} = \frac{250^2}{0.25 + 0.25} = 125\text{k}\Omega$$

We select $R_1 = R_2 = 68\text{k}\Omega$.

$$i_{in,min} = \frac{V_{min} - 1.65}{2 * R_1 * 1.05} = \frac{198.35V}{142.8Kohm} = 1.39\text{mA}$$

The output stage:

$$i_C \geq i_{in,min} * CTR_{min} \approx 1.39mA * 0.34 \approx 0.47mA$$

$$i_{leakage} \leq 1uA$$

$$V_{IL} = 0.3Vcc = 0.3 * 5V = 1.5V$$

$$V_{IH} = 0.6Vcc = 0.3 * 5V = 3V$$

If we strive to be below 1V for logic zero:

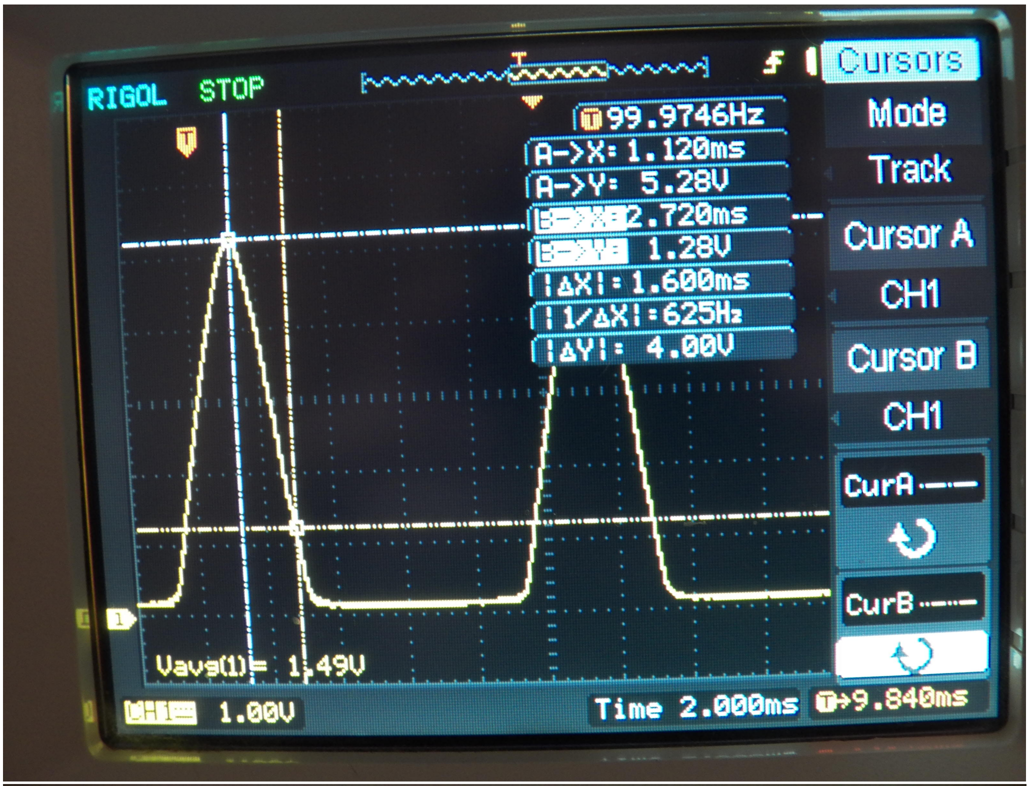
$$i_C * R_{output} = 1V$$

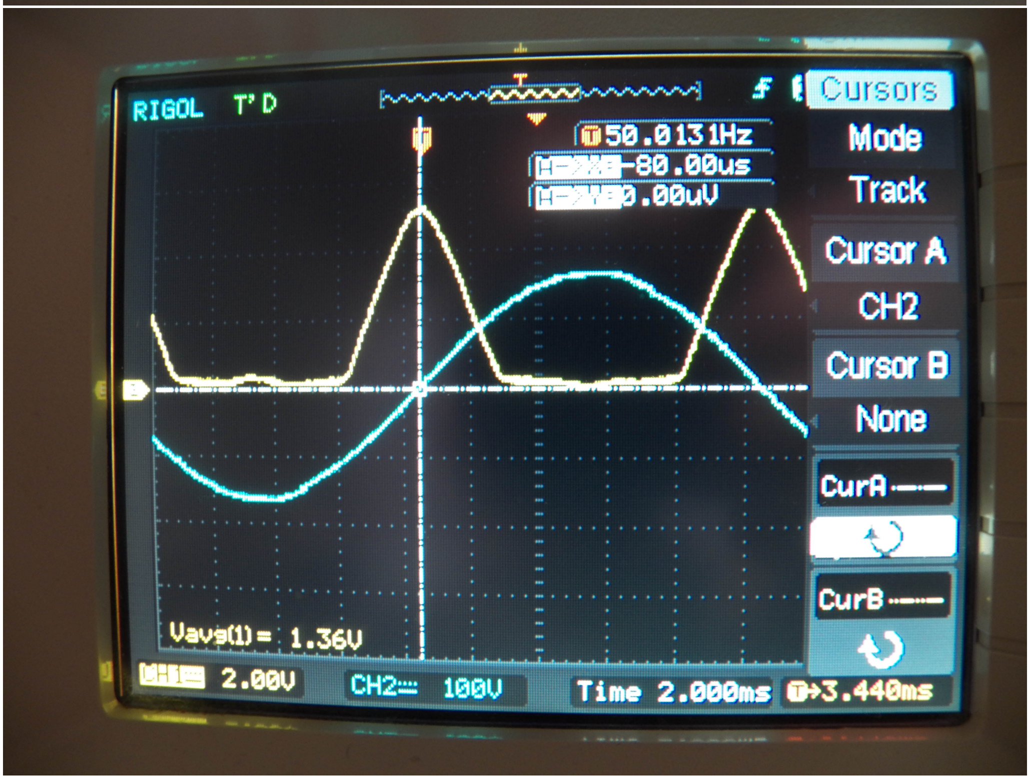
$$R_{output} = 1V/0.47mA = 2.13Kohm$$

We select $R_3 = 2.4\text{k}\Omega$.

1.4.3 Measurements

Firstly, a temperature measurement is performed. The device is allowed to run for 10 minutes. Subsequencly, each component is measured or overheating. Becuse component temperature measurement instrumentation is both expensive and dfficult to apply, the following rule of thunmb is used: *if a silicone component is too hot to keep your finger on it, it is too hot*. Althought the stated metod is vastly imprecise, it works well, because the skin pain temperature (about $60°$C) is far lower than silicone semicondutor Absolute Maximum Temperature (often $150°$C).





We observe that:

1. The pulse is very wide - about 3.2ms ≡ 32% of the half-period.
2. The puslse is centered. This is great, because we can estimate the true zero crossing

in software.

1.5 Thermometer

It is impossible to examine the temperature sensing element in isolation to the heater. Therefore, in this chapter, the complete plant, or in other words the combination of heater, thermal mass and thermometer, will be examined.

As this is an educational project, the quickest possible system responce is desired. Therefore, the thermometer is directly gued to the surface of the heater. Unfortunately, even in this setup, the maximum possible heating rate is about 6°C/min and cooling is even slower.

1.5.1 Heater

Initially, a 60W incandescent light bulb was selected. As European wall power exhibits frequency of 50Hz, the highest switching frequency is 100Hz by half-periods. Astonishing to the experimenter:

- The fillament is not inert enough to integrate consecutive pulses, even if every odd half-wave is enabled.
- The human eye is unable to integrate the resulting 50Hz flicker.

As a result, looking in the controlled bulb is extremely annoying.

Consequenctly, a fish tank heater with nominal (maximum) power of 50W was selected. The observed temperature curves are equivelent sans the maddening light flicker. **The thermometer is glued to the surface to the heater for fastest response possible.**

1.5.2 Temperature sensor

The Dallas Semiconductor DS18S20 has been selected due to a variety of reasons:

- low price
- ease of interfacing to digital components
- ease of wireing
- extreme flexability of integration

This device is incedible. It can operate solely over two wires - including the ground wire. It performs digital temperature conversions, removing the need of an ADC (although our selected microcontroller features such). It can coexist on the same bus with as many as $2^{56} \equiv$ infinite number of other onewire sensors.