ME 220 Term Paper

APPLICATION FOR UNITED STATES LETTERS PATENT

Title: POWER INDEPENDENT TEMPERATURE SENSING FRYING PAN

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POWER INDEPENDENT TEMPERATURE SENSING FRYING PAN

ABSTRACT

This is the final term paper for ME 220. It is in the form of a patent application; as the product discussed below is novel and this format is effective in delineating its design. This application describes a design for a stove top frying pan (or pot) that simply determines the current temperature of its surface. As a matter of practicality, the design also includes a Peltier module that acts as a thermogenerator so that the pan can power itself.

FIELD OF THE INVENTION

[**0001**] The current field relating to electronics in cookware is quite extensive. For example, products like the Instant Pot, Nespresso, Bullet blender, and more have all improved upon an existing method of cooking by adding technological features. There has yet to be such an innovation for stove-top cooking ware. There do exist designs such as [1], a patent for a frying pan that requires no stove and senses both the pan and food temperature. This design, however, has not seen commercial success in part because it requires power and because it provides elaborate solutions to problems that do not exist.

[**0002**] The present invention also relates to the market of thermoelectric generators. The product relates to Peltier modules and thermocouples in its use of the Seebeck effect to generate power. A common commercial design relating to this are heat powered stove top fans [2].

[**0003**] In terms of cost, this product will lie in the category of high-end cookware, where pots and pans can range in cost between $200 and $600.

BACKGROUND OF THE INVENTION

[**0004**] By its nature, cooking and baking is a practice dependant on a cook's ability to control the temperature of his food. On one hand, ovens provide a great deal of control and certainty of temperature. On the other, the prefered method for stove top cooking is with gas burners, which, by the nature of an open fire, carries far less certainty of the temperature of the pan or pot that is being heated. Many chefs rely on behavior and sound of water or oil being dropped on the pan to estimate its surface temperatures. Others opt for tools such as hand-held infrared thermometer.

This product is especially useful for professionals. The global commercial cooking market is a $10 Billion industry [3]. In addition, there is a great deal versatility of the product that we describe below: because it does not require external power, such a design can be used in scenarios such as camping trips, where it would be inconvenient to provide power. For this reason, there is also potential to break into the $59 Billion personal cookware market [4]. We would estimate that this product can fill a need in the market and assume 0.5% of these market shares, implying a product-line valuation of $350 Million.

[**0005**] What is needed is an embedded solution: a pan or pot that can measure its own surface temperature. Such a device will enable much more certainty to the cook, both amateur and professional, the temperature at which he is cooking. This way there is no guessing or estimation or second device required to cook even the most temperature-sensitive dishes.

SUMMARY OF THE INVENTION

[**0006**] The main objective of the invention is to create stove-top cookware that will display its current surface temperature and require no power or charging otherwise from its user.

[**0007**] To accomplish these objectives the invention specified has two main components each of which is a novel solution. The first is primarily the mechanical design that utilizes the temperature differential between the handle and base of the frying pan to generate its own power. The second is primarily the electrical design of an embedded system that measures surface temperature of the pan and displays the current temperature on an LED display.

DRAWINGS AND FIGURES

[**0008**] Fig. (A) is a representation of the layout of the key components. Feature (1) is the LED Display on the hollow-cast stainless steel handle. Feature (2) are the heat-conducting, electrical-insulating substrate of ceramic that facilitates the heat differential of the thermoelectric generator (TEG). Feature (3) are the copper electrical-conductive plates that connects the thermocouples. Feature (4) is the array of p and n doped thermoelements. The dimensions of the TEG is 10 cm x 6 cm x 1 cm, with an array of 80 thermocouple elements. Feature (5) is the temperature sensing thermocouple embedded in the body of the pan.

[**0009**] Fig. (B) is referenced from [5]. It illustrates the ceramic insulating and copper conducting layers of a peltier unit connecting with the p and n doped thermo couples. This is representative of the TEG seen in feature (4) of FIG.[A].

[**0010**] Fig. (C) is a block diagram of the overall system, split into the electrical components inside the handle and components in the body of the frying pan.

[**0011**] Fig. (D) is a schematic of the electrical design. The schematic includes possible options for individual components, all of which fulfill power requirements. In addition, it provides the right IO ports to be able to interface with the TEG, a battery, the LED screen, firmware programming, and the temperature-sensing thermocouple.

[**0012**] Fig. (E) is a bill of materials for the components seen in Fig. (D) in addition to a battery and led screen.

DESCRIPTION OF POWER GENERATION COMPONENT

[**0013**] The main feature of a pan, of which we hope to take advantage, is the heat differential between the base and the handle of the pan. Pans with hollow-core cast stainless steel are highly resistant to temperature change because of an insulating pocket of air inside the handle. This means that, even as the pan may get as hot as 300°C, the handle only reaches a temperature of at most 50°C. By placing a thermo-electric generator between the base of the pan and its handle, where the handle acts as a heat sink, this will allow for a maintained heat differential of 50 to 250C.

[**0014**] This thermo-electric generator will work by taking advantage of the Seebeck effect to generate power, described by

$$I = \frac{\alpha \Delta T}{R_L + R} \tag{1}$$

$$V_n = \frac{n\alpha(\Delta T)}{R_L + R} R_L \tag{2}$$

$$P_n = V_n I[5] \tag{3}$$

where α is the Seebeck coefficient for the thermoelements with units V/K; I is the current for an internal resistance R and load resistance R_L; V_n is the voltage across R_L for n thermoelements; and W_n is the power. We can calculate internal resistance R with equation

$$R = \frac{\rho L}{A} \tag{4}$$

where ρ is the resistivity of the thermoelement.

[**0015**] We place an array of 80 thermocouples (one n-type and one p-type). Using silicon for the thermocouples, the Seebeck coefficient is $\alpha_p = -\alpha_n = 400\mu V/K$ [6]. To give an extreme, we have a load of $R_L = 10\Omega$, and a silicon resistivity of $\rho = 5\Omega m$. With equations (1), (2),(3), and (4), we can determine the characteristics of our power generator:

$$R = \frac{(5\Omega m)(1cm)}{(10cm)(6cm} = 8.34\Omega \tag{5}$$

Using a range of possible temperature differentials of $\Delta T = [50, 250]$ we get ranges and n = 80:

$$V_n = \frac{(400\mu V/K)(2*n)(\Delta T)}{(R+R_L}R_L = [1.74, 8.72]V. \tag{6}$$

$$P_n = [1.897, 5.45]mW. \tag{7}$$

Therefore, while there is a wide range of power, it can be seen in the next section, that such a TEG unit can provide more than enough power to the embedded system.

EMBEDDED SYSTEM AND SENSOR SELECTION

[**0016**] Referring to Fig. (C) and and Fig. (D), there are 6 main blocks to consider.

First, because we have such a large range of voltages being supplied by the TEG, we want to utilize a voltage regulator to provide a constant 5V out to the power management IC (PMIC). Note: as discussed in the last section, the voltage may not always be high enough to turn on the voltage regulator. We need the heat to be approximately 170 C. This makes it necessary to include a battery to be able to use the pan at low heats.

Second, we have our PMIC which charges our 3.7V Li-ion battery and also provides Vcc for the rest of the circuit.

Third, we have the MCU: of which we require an ADC and I2C capabilities. The MCU will run off of the 3.7 volts provided by the PMIC and it will communicate with the LED screen driver.

Fourth, we include an opamp which will be used as a buffer for the voltage sense from the thermocouple. This will be discussed later in this section.

Fifth, we include a driver for the 4 digit 7 segment display to be able to display temperature accurately on the order of 1 °C.

Finally, we want our device to turn on when placed on the burner. Even a small voltage will turn on the switch, and, therefore, it allows power to run from the PMIC to the MCU even when the pan is simmering.

[**0017**] There are many ways to measure temperature, so determining the right sensor that aligns with our usecase is important. We chose to use a thermocouple over a thermistor because, even though thermistors often provide more sensitivity, such sensitivity is only effective in a small and low temperature range. By the Seebeck Effect, thermocouples, although less sensitive work at much higher and broader range of temperatures.

There are many types of thermocouples, with the main differences being the types of alloys used, giving them different properties. For example, a T type thermocouple has copper and constantan elements and is often used at extremely low temperatures, while a B type thermocouple, with Platinum-Rhodium elements are used at extremely high temperatures [7].

We opt for the common K type thermocouple, with Nickel-Chromium and Nickel-Alumel elements, choosing it for its wide range of measurement, reliability, availability, and cost effectiveness. A good solution is [8], a K type thermocouple from Adafruit. It is both cost effective and packaged well enough (with an insulated cable rated high enough to protect it from the heat) to be embedded in our cookware. (Data sheet is not included in this paper, as it provides no added information, but may be referenced below).

K type thermocouples are very well defined. With the extremes on temperature defined above: $\Delta T = [50, 250]$, our sensor will output will be between $V_out = [2.023, 10.15]V$, incriminating by about $20mV/K$ [7].

We will try to embed this sensor as close to the center of the pan as possible, which is likely indicative of the average temperature of the surface of the pan.

[**0018**] This leaves us with two problems to solve, with solutions illustrated in the block diagram and schematic below.

First, we have an MCU that is powered with $3.7V$ VDD. This means that for measurements from the thermocouple greater than $3.7V$, we would surely not be able to accurately determine temperature. If we consider the MCU chosen in in Fig. (D), a Microchip PIC161455, with $Vdd = 3.7V$, the 12 bit ADC operates at $2.048V$. Split among 12 bits, this gives us a resolution of $0.5mV$. The solution introduced in the schematic is to decimate the signal so that the readings into the ADC are in range $V_in = [0.2023, 1.015]V$, so that we are now inside the range of the ADC's rails.

Note: we now increment by $2mV/k$, still well within the capability of the ADC's $0.5mV$ resolution.

Second, we want to make sure that we are not altering the voltage by possible leakage current from measurement. Therefore, we include an opamp that acts as a unity buffer between the sensor and the ADC.

[**0019**] Finally, it is relevant to breifly mention the firmware. The only requisites of our firmware is to periodically read from the ADC. This voltage can then be turned into a temperature from an internal look-up table. Then the appropriate lighting for a 7 segment display must then be determined (also likely from a look-up table). Finally, the MCU must send this information to the LED display driver over I2C. Luckily, because we are dealing with heat measurements, none of our devices have much of a speed requirement: each measurement can be as slow as 1/2 second.

COST ESTIMATE

[**0020**] The specific components chosen for the design in Fig. (D) all follow power requirements and those stated above. This paper will not discuss the decisions for each component, other than to say that this is a viable design from which we can derive a cost estimate. All prices below assume no economies of scale and a limited production run as is appropriate for building a working prototype. The ultimate cost will also not include cost of labor, manufacturing, or other costs associated with a business.

[**0021**] Given current prices of copper and stainless steel, we estimate that the material of the pan will cost around \$10. In addition, the size of our proposed TEG is roughly that of 3 standard peltier modules such as [9], which would total around \$12.

With the total given to us by the BOM in Fig. (E), our project has a total cost of around \$65.74. As we've discussed above, a high end pan sells for more than \$200, leaving us with a great deal of profit margin for which labor and manufacturing can be accounted.

What is Claimed:

1. Thermoelectric generator that uses a pan's body as a heat source and its handle as a heat sink
2. A novel power management circuit that utilizes power generated from a Seebeck generator
3. Embedded thermocouple, processor, and display inside cookware to inform user of the cookware's temperature

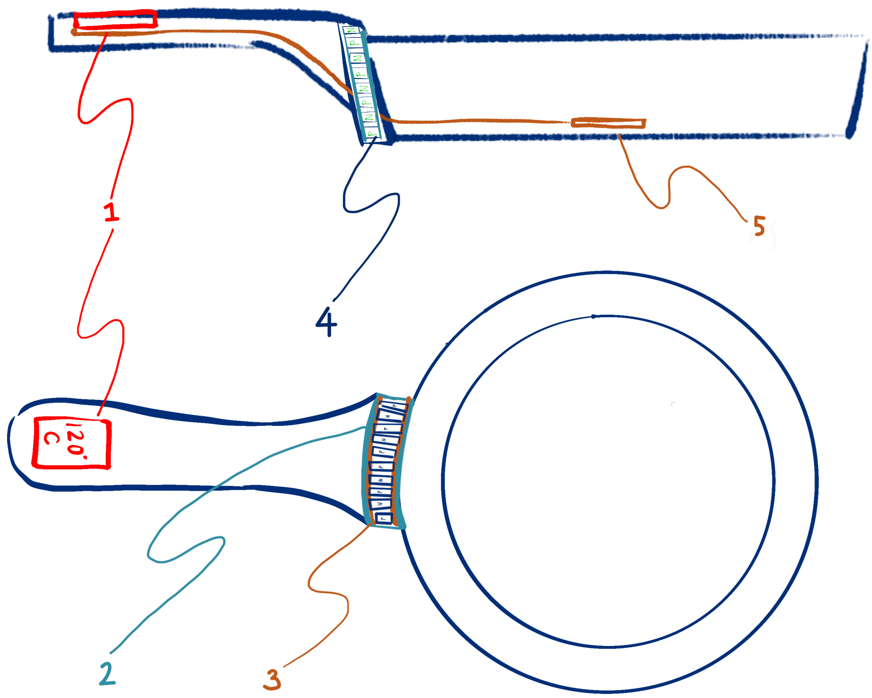

Figure A: Overview of mechanical design

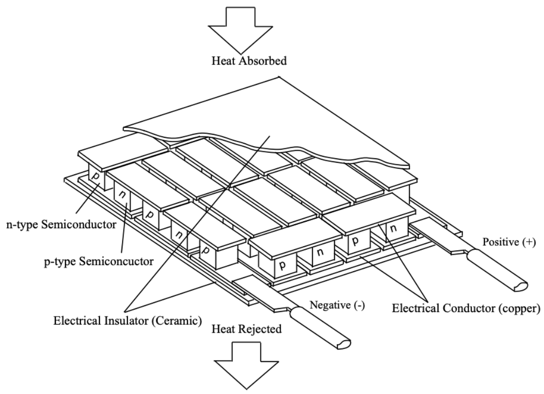

Figure B: Example TEG design

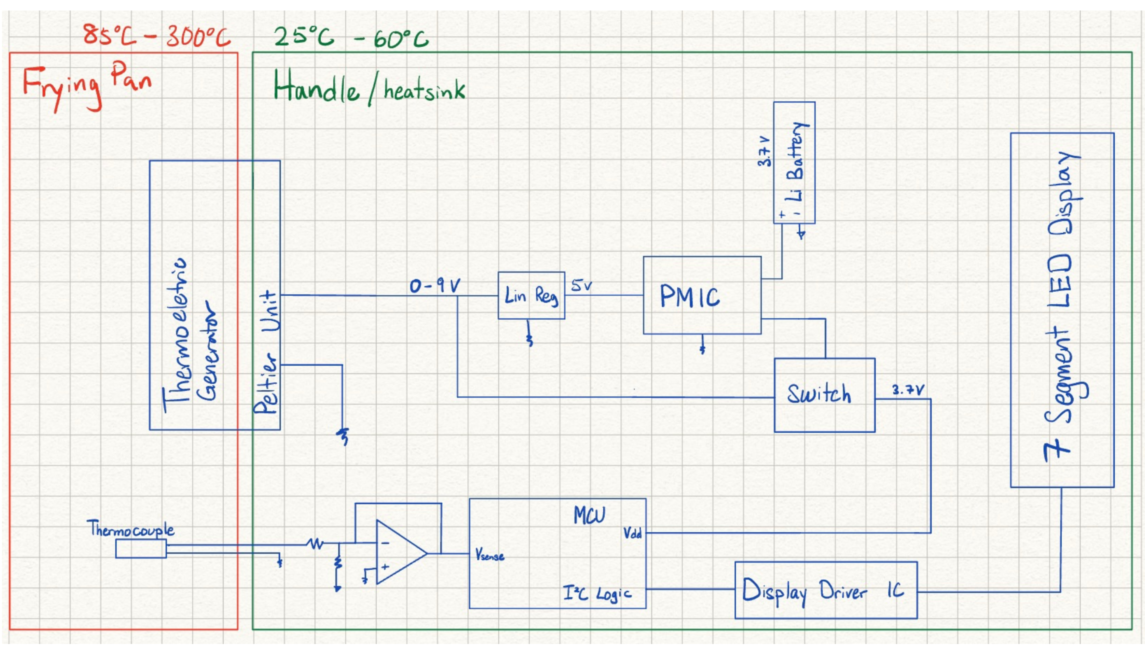

Figure C: System block diagram

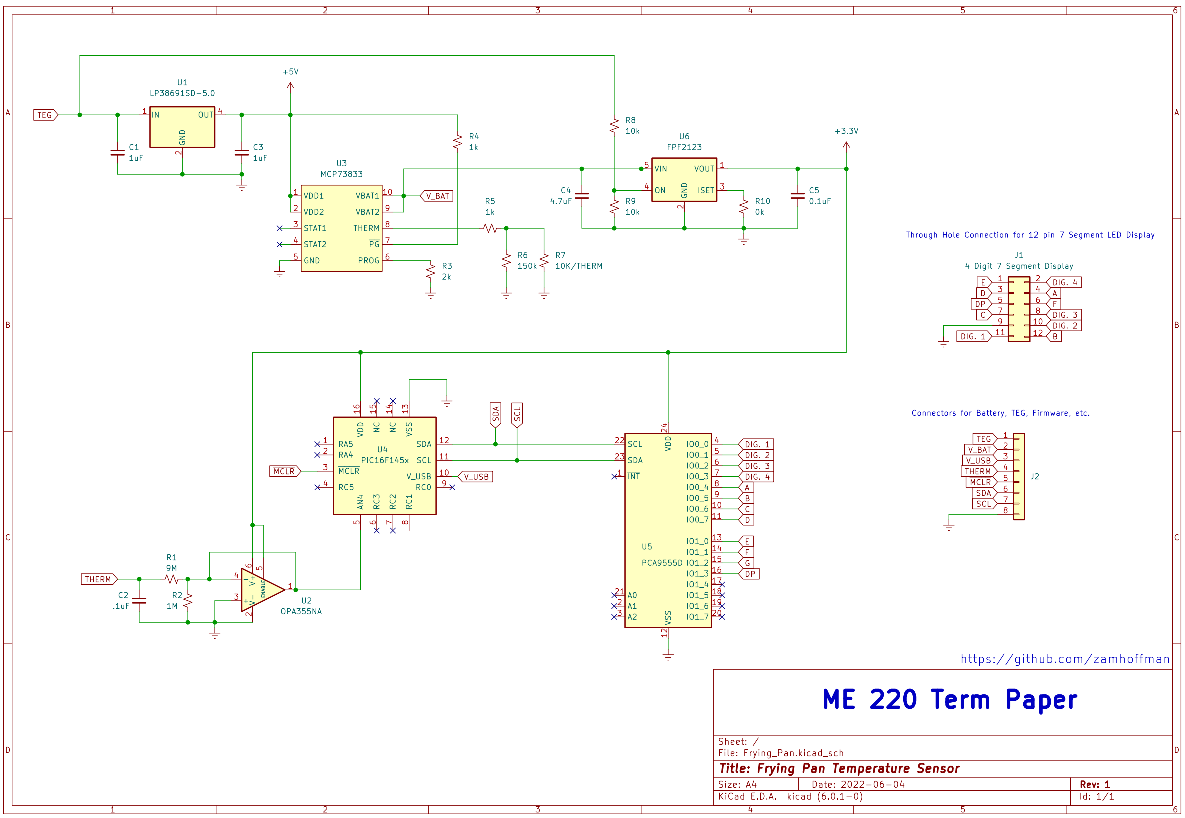

Figure D: Schematic for power supply, temperature sense, and LED display control

Qty	Reference(s)	Value	Price
1	C2	.1uF	0.4
1	C4	4.7uF	0.75
1	C5	0.1uF	0.4
1	J1	4 Digit 7 Segment Display	0
1	J2	Conn$_{o}ut$	0
1	R1	9M	0.4
1	R2	1M	0.4
1	R3	2k	0.4
1	R6	150k	0.4
1	R7	10K/THERM	0.4
1	R10	0k	0.4
1	U1	LP38691SD-5.0	2.27
1	U2	OPA355NA	2.08
1	U3	MCP73833	2.54
1	U4	PIC16F145x	2.3
1	U5	PCA9555D	0.89
1	U6	FPF2123	0.76
1		3.7V Li-ion Battery	5.95
1		7 Segment Display	1.5
1		PCB	10
1		K-Type Thermocouple	9.1
		Total	43.74

Figure E: Bill of Materials for the embedded system

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