An Inexpensive Microelectronic Environmental Test Chamber

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Abstract—**An inexpensive microelectronic environmental test chamber design is proposed that can vary the temperature with a range of greater than 10°C to 90°C. The chamber is capable of automating temperature cycling as well as automating the electronic measurements taken. Driven by thermoelectric devices, the chamber is exceptionally space efficient and flexible in use; occupying an area of less than 1.5 cubic feet and powered by a standard wall outlet. The total cost of such a unit is less than a fraction of the average cost of a typical industrial built unit.**

Index Terms—**Environmental Test Chamber, Thermoelectric Coolers, Temperature Testing**

I. Introduction

As the demand for increased performance from common electronic devices continues, the testing procedures for even simple microelectronic devices become more complex and more costly. In particular the need to test in different environmental settings has become increasingly important for not only analog designs but also for VLSI designs. One of the largest effects that is in exploration is temperature. In analogue processes this is chiefly studied upon voltage references. The chief concerns of environmental chambers include: 1) the high cost associated with the purchase and operation of a environmental chamber, 2) the accuracy of the reading of the internal temperature, 3) the time it takes to make a measurement and automation to allow for multiple temperature conditions, and 4) the special considerations for a system that uses liquid cooling methods or unique power needs.

It is the purpose of this paper to propose an inexpensive environmental chamber solution used to accurately control the temperature between 10°C and 90°C. Thermoelectric Coolers (TEC) were used for the cooling and heating devices. This chamber is capable of producing a temperature cycle that can accurately control the chamber's temperature using a USB interface and associated programming. This automation also allows for an automatic circuit measurement.

II. Thermoelectric Coolers

Thermoelectric Coolers are simply P-N junctions developed using two dissimilar metals. As current is passed across this type of junction, one side of the junction needs to elevate the electron band to a conduction level. The energy used to do this is thermal energy. At the same time the other side generates heat from the current passing across its conduction band. Consequently one side gets cold, and the adjacent side gets hot. It is in this insight a TEC can be viewed as a heat pump. The "pump" direction can be reversed using a different polarity in voltage.

The performance of a TEC is typically characterized by four parameters: U_{MAX}, I_{MAX}, Q_{MAX}, and ΔT_{MAX}. Each of these parameters characterizes an extreme capability of the device. U_{MAX} and I_{MAX} refer to the electrical power needed to power the device. Q_{MAX} refers to the maximum heat that the TEC is capable of "pumping" assuming 100% efficiency. ΔT_{MAX} is the maximum temperature differential that the TEC is capable of producing between the cold side and the hot side.

A typical value seen for ΔT_{MAX} is roughly 70°C. In the same way a voltage is a differential, ΔT_{MAX} indicates temperature as a *differential* and it is necessary keep a single side of the TEC as reference. Therefore to achieve a cooling or heating effect the reference side is held at ambient or room temperature. This can be successfully achieved through forced convection with a micro-channel heat sink. This method of heat dissipation is capable of dissipating large quantities of heat. The heat the TEC is capable of pumping is also a concern. As in all thermodynamic system, the enclosure strives to reach equilibrium. To achieve a net increase or decrease in temperature the ability of the TEC must be higher than the net heat loss of the enclosure used. At the desired ΔT, a Q_{MAX} must be determined to understand how well built of enclosure must be necessary. The final concern is in the time necessary to achieve a given temperature. This is a function of the Q_{MAX} of the TEC, enclosure size and heat loss, and number of TEC modules. Table 1 shows the performance parameters of the TEC modules that were used.

TABLE 1
Performance Parameters of Frost-74 TEC

Parameter	Value (Units)
I_{MAX}	6.3 Amps
U_{MAX}	16.7 Volts
Q_{MAX}	65 Watts
ΔT_{MAX}	74 Celsius

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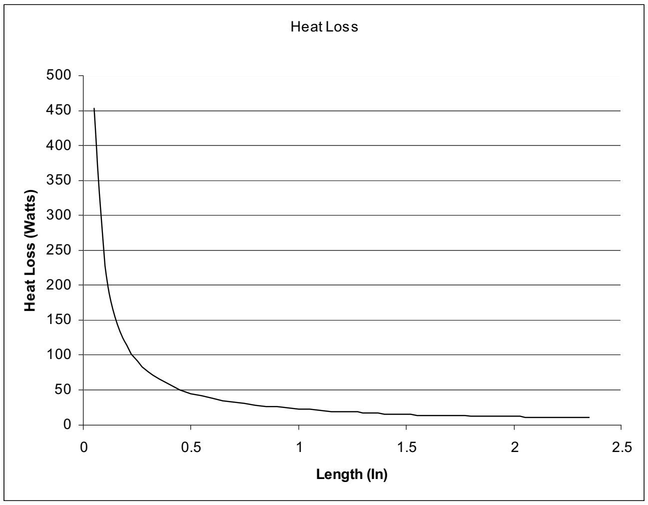

Fig. 1. Heat loss of Enclosure VS Length of Insulation

III. ENCLOSURE

The construction of the enclosure is of particular importance in how well the chamber will be able to operate. An enclosure size of roughly 1 cubic foot was chosen to reduce the time of achieving a temperature. The interior of the enclosure is composed of a thermally conductive material to promote uniformity in temperature throughout the enclosure. The method in which the interior achieves the temperature of the TEC is also forced convection using a heat sink. The interior fans also work to stir the air and create temperature uniformity. The insulating properties of the enclosure come from the exterior. The exterior is composed of an insulating substance, extruded polystyrene foam. The heat transfer through the walls of the enclosure takes the form of (1) [1]. This relationship is shown in Fig. 1.

$$Q = \frac{\Delta T}{L / kA} \tag{1}$$

The thermal resistance of the insulating material and the thickness determine the heat loss assuming the enclosure is constructed airtight. The approximate thermal resistance used for this material was 0.660375 $m^2 \cdot K/W$. Choosing a thickness of 1.5 inches, a heat loss of 15.13 Watts is expected. After the insulation is added along with an outer shell, to protect the insulation, the total outer enclosure area is less than 1.5 cubic feet.

IV. CONTROL ALGORITHM

The power supplied to the TEC modules has an almost linear relationship with ΔT achieved. With this known there are a number of control algorithms that can be implemented. Utilizing a USB interface data acquisition card, standard 12 volt power supplies, and accurate temperature sensor ICs, it is possible to simply program an algorithm. Possible algorithms that were considered include: Proportional Integral (PI), Proportional Derivative (PD), Proportional-Integral-Derivative (PID), and Bang-Bang Control.

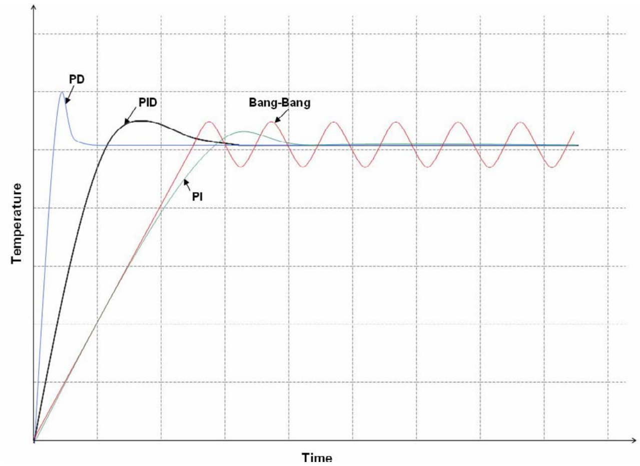

Fig. 2. Transient Response of Control Algorithms Considered

Commonly sought over PI and PD, the PID control algorithm contains properties that make it a better choice. Within a transient response, the PI system presents no overshoot, but takes a very long time with to achieve the given temperature. PD system presents the opposite challenge; a transient response that contains much more offshoot and quite possibly ringing. It is however a faster response. The PID combines both systems [3]. This controller is the typical choice for TEC control. The typical control system for an environmental chamber is the Bang-Bang Algorithm. This system contains two error boundaries surrounding the desired temperature and only corrects when the signal exceeds either boundary. The limitation of this system is that it allows for a "ripple" transient step response. The transient step response of each system can be seen in Fig. 2.

Given the speed of the data acquisition card, 10kS/s, and the accuracy of the temperature sensor used, 2°C, the Bang- Bang and the PID control algorithm can both be very feasible options and promise to provide accurate result. Other benefits from this implementation include automation of taking test data from the microelectronics under test.

V. PERFORMANCE AND TESTING

After construction, the environmental chamber was tested for the extreme temperature situations. This is performed by applying a constant power to the TEC modules and observing the internal temperature over time. The power supplied to the TEC modules was at approximately 1.5 Amps and 3 to 6 Volts. This is approximately 25% of the I_{MAX}. This lowers the capabilities, Q and ΔT, of the TEC by nearly 50% [4]. The results for heating and cooling can be seen in Fig. 3 and 4.

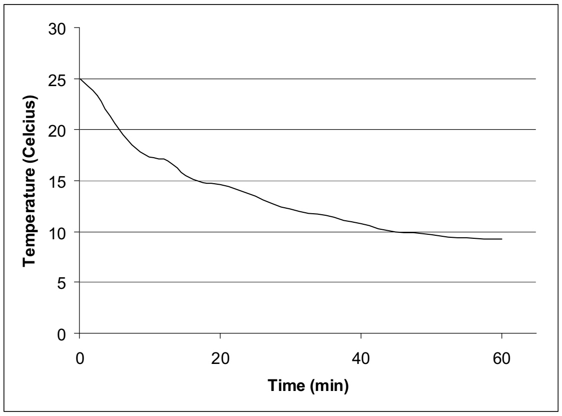

Fig. 3. Enclosure Cooling Performance

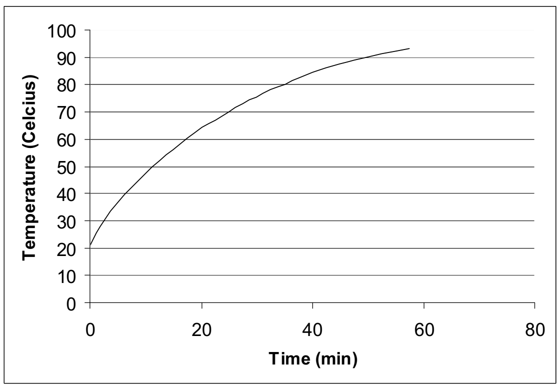

Fig. 4. Enclosure Heating Performance

This measured data indicates the heat loss is approximately 16-17 Watts based upon the manufacturers expected performance. This is roughly what was expected from insulating calculations referenced earlier. This is a very good indication that the thermoelectric environmental chamber can achieve a much larger temperature range.

VI. Conclusion

An Environmental Test Chamber for microelectronics was presented displaying a range of 9°C and 94°C. The chamber displayed many desirable traits including minimal cost, minimal space, and flexible automated controls and data gathering.

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