Rebirth of Iconic 60's Technology: Dynamically Lighted, Closed-Loop Temperature Controlled Lava Globe

Mock Design Review

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1.0 Block Diagram

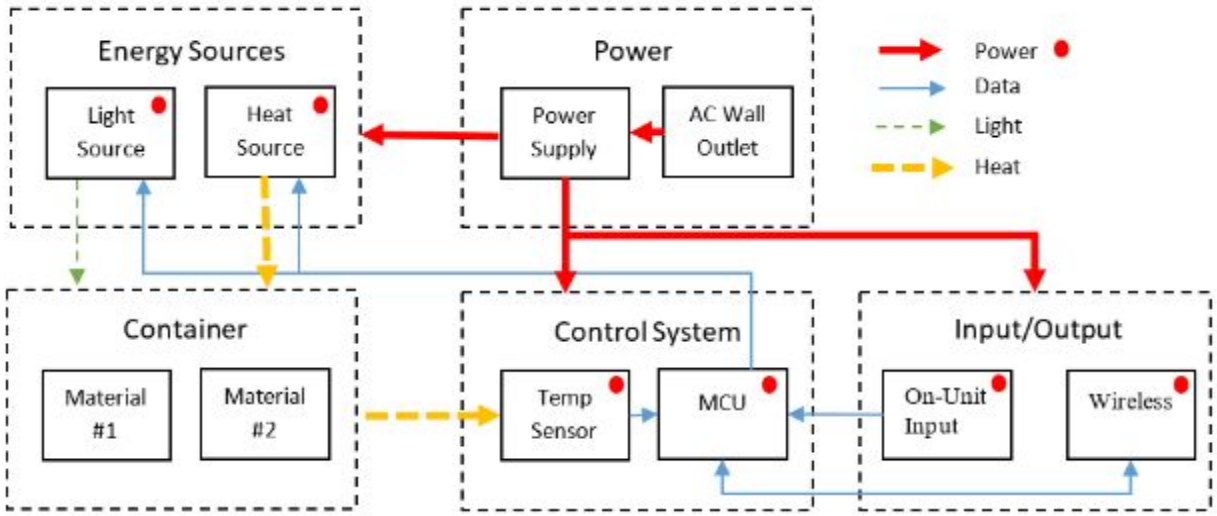


Figure 1: Lava globe block diagram

2.0 Heat Source Circuit Schematic

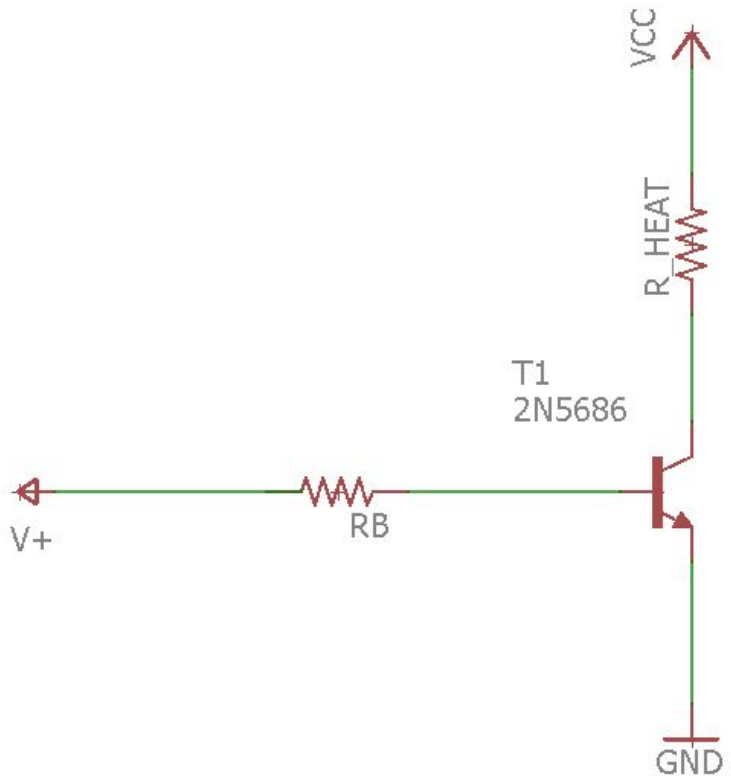


Figure 2: Heat Source Schematic

3.0 Calculation of Heat Source Component Values

As noted in the requirements and verification section below:

$$P_{R_{HEAT}} \geq 60W$$
$$\boxed{V+ = 5V}$$
$$\boxed{V_{cc} = 20V}$$

To control and source the required current we must use a power transistor. The 2N5686 (NPN) transistor does the job. From the datasheet we find it has the following relevant values [1]:

$$V_{BE(on)} = 2.0V$$
$$V_{CE(sat)} = 2.0V$$
$$\beta = 120\ (@\ 25\ ^{\circ}C)$$

Recalling the Equations of an NPN BJT in Forward Active mode:

$$IF\ V_{BE} \geq V_{BE(on)} \quad AND \quad B - C\ is\ reverse\ biased$$
$$THEN \quad I_C = \beta I_B$$

If we set V_{CE} =2.0V because that is where we know all of our values, then:

$$P_{R_{HEAT}} = \frac{{V_{R_{HEAT}}}^2}{R_{HEAT}} \geq 60W \ \rightarrow \ R_{HEAT} \leq \frac{(18\ V)^2}{60\ W} = 5.4\Omega$$

$$Choose\ \boxed{R_{HEAT} = 5\Omega}\ to\ have\ some\ room$$

$$I_C = \frac{V_{R_{HEAT}}}{R_{HEAT}} = \frac{18\ V}{5\Omega} = 3.6\ A$$

$$I_B = \frac{I_C}{\beta} = \frac{3.6A}{120} = 30\ mA$$

$$R_B = \frac{V_+ - V_{BE}}{I_B} = \frac{5\ V - 2\ V}{30\ mA} = \boxed{100\Omega = R_B}$$

The power requirements for the resistors are therefore:

$$P_{R_{HEAT}} = I^2R = (3.6\ A)^2(5\ \Omega) = 64.8\ W = P_{R_{HEAT}}$$
$$P_{R_B} = IV = (3\ V)(30mA) = 90mW = P_{R_B}$$

4.0 Simulation

To determine the feasibility of a spherical lava globe, a thermal study on the design was performed. We want to show it is possible to heat the globe to an appropriate temperature (60°C) without applying so much heat to the glass that it fractures. In figure 3, we model the contents of the globe as non-fluid water and heat it from below by 90W. Without accounting for convection, the 90W source heats the globe well.

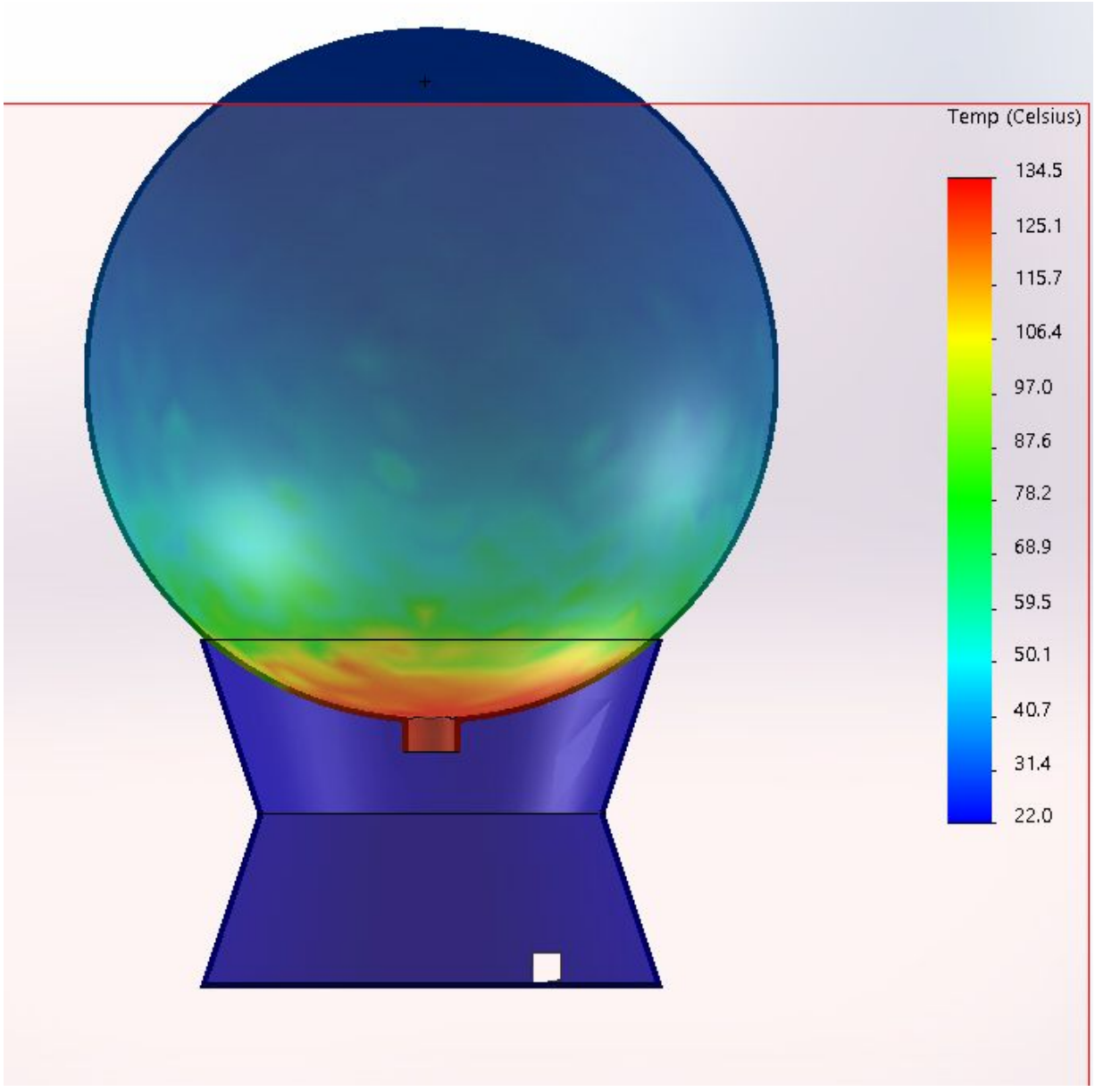


Figure 3: Solid body study of spherical design, 12” diameter globe heated with 90W steady state

Without the convection currents, the model is not very accurate. In figure 4, we simulate with convection and reach an average temperature of 57°C.

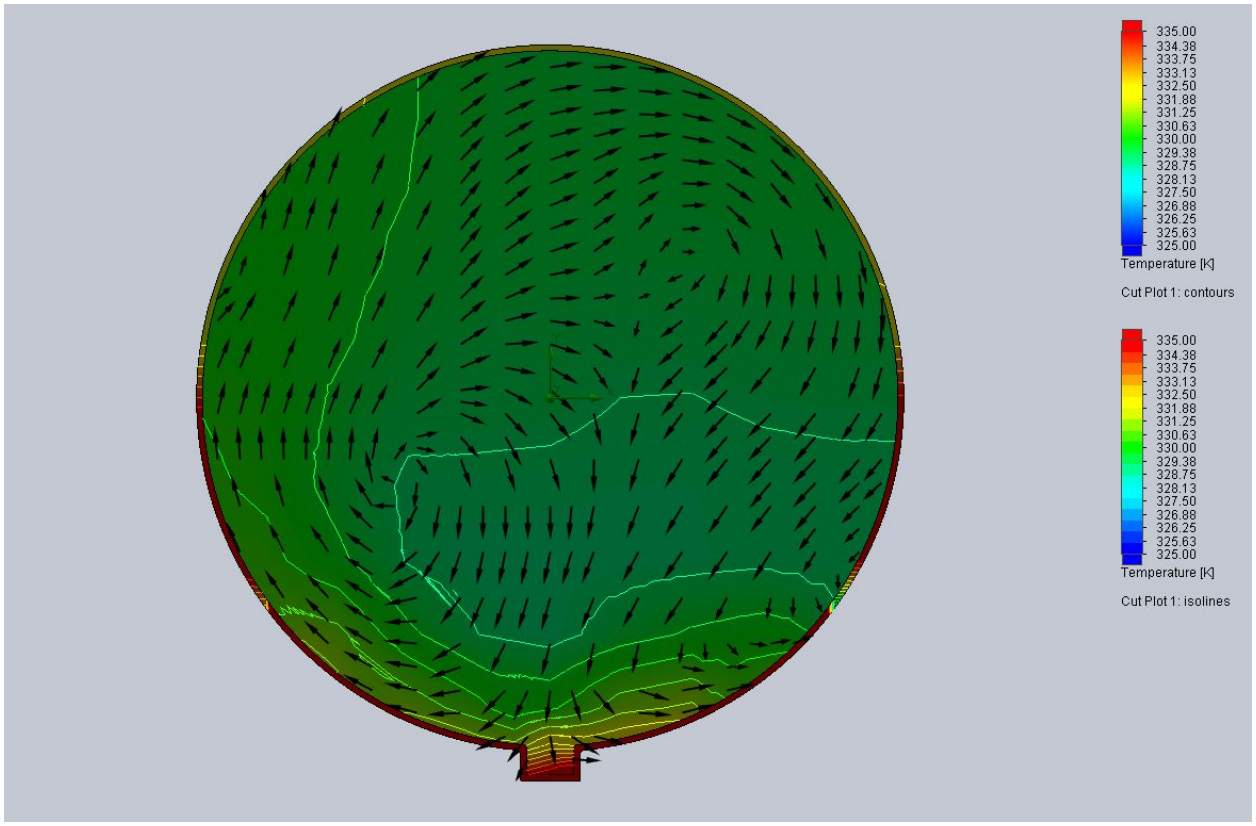


Figure 4: CFD study on 12” diameter globe water convection heated by conductive heat source

5.0 Heat Source Block Description

The heat source receives a signal from the MCU and power from the power supply. The heat source consists of a power transistor, power resistor, and a current-controlling resistor. The signal from the MCU is a PWM waveform with a specific duty cycle used to control how much heat is produced by the power resistor. The power can range from 0W to 60W depending on the duty cycle. The heat is conducted to the lava globe over an air gap.

6.0 Requirements and Verification of Heat Source

Requirements	**Verification**
1. Must dissipate between 60W and 70W of power when operated at 20V without damaging the module for at least 1 hour.	1. Verification for item 1 a. Connect an ammeter inline with the heat source to a lab power supply at 20V b. Confirm that the heat source sinks between 3A and 3.5A c. Supply a control signal to produce maximum power d. Verify it doesn't catch on fire, blow up, or anything else bad for the next hour
2. Must be able adjust power in increments of 1W	2. Verification for item 2 a. Connect ammeter as above b. Use control to step power up by smallest increments. c. Record the current as above and repeat d. At least 6 levels should have been recorded, each differing by less than 1W

7.0 Safety Statement

The safety issues of our device are electrical, chemical, and thermal in nature. During the development phase team members will be at risk of strong electrical shock. We will minimize this risk by utilizing proper lab electrical safety measures such as removing power from circuits currently not in use and testing circuits for power with an ammeter before we start using them. We also intend to use the lab bench for the majority of our development to avoid the hazards posed by using an AC wall socket directly. The lab bench will offer us more precise control over what is going in and out of our circuits. Finally, we will not bathe with the lava globe, as electricity and water are a dangerous combination, and we will advise others to do the same as required by the first point in the IEEE Code of Ethics [2].

The chemical hazard stems from using possibly unsafe materials inside of the lava sphere. The hazard presents itself if the sphere integrity is compromised and a leak occurs. We do not intend to use chemicals that are unsafe to the touch, but they may be unfit for human consumption. Accordingly, we will not try to eat the chemicals if they escape the sphere, and we will also provide a warning label to warn others to also not eat the chemicals from the sphere.

The most significant and likely safety issue is the threat of thermal burns. We expect the lava globe sphere to require a temperature of around 150°F to function correctly. These temperatures are enough to cause contact burns within a second of contact [3]. Therefore, we will do our best to not touch the sphere when it is operational and we will create a warning label to warn others to do the same.

Another issue related to thermal safety is that as the temperature inside of the sphere increases the pressure will also increase, thereby creating an explosion hazard. Our lava globe will have thermal control features to prevent the temperatures from rising above the 150°F operating temperature. We intend to make the temperature control circuit robust enough to ensure that the risk of explosion is negligible.

8.0 Citations

[1] On Semiconductor (2016, September 21). 2N5686 Datasheet [Online]. Available: http://www.onsemi.com/PowerSolutions/product.do?id=2N5686

[2] IEEE. (2016, September 20). 7.8 IEEE Code of Ethics [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html

[3] Burn Foundation (2016, September 20). Safety Facts on Scald Burns [Online]. Available: http://www.burnfoundation.org/programs/resource.cfm?c=1&a=3