MMIC TEMPERATURE STABILIZATION THROUGH PHASE CHANGE ENERGY ABSORPTION

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ABSTRACT

A new temperature stabilization concept for MMIC's utilized in applications such as Decoys, Kinetic Energy Weapons, Missile Systems, and Smart Munitions is presented. The concept permits MMIC junction temperatures to be maintained within operational limits during short periods of high power dissipation. The stabilization of junction temperature is accomplished by locating the MMIC in close thermal proximity to a material which undergoes a change of state. The result of this mounting configuration is the absorbtion of large relative quantities of thermal energy within a minimal volume. Both theoretical and experimental data are presented which support evidence of an increase in operational period of approximately two hundred percent.

INTRODUCTION

Decoys, Kinetic Energy Weapons, Missile Systems, and Smart Munitions require the integration of a large number of components within a small system package. A high concentration of functional integration is typically accomplished though the use of MMIC technology. The incorporation of MMIC's has increased the dissipated power densities to the point where system performance has become thermally driven. In addition to the MMIC's electrical performance requirement, the military requirement to operate at relatively low junction temperatures has forced the system designer to consider new and innovated methods for maintaining a stable operating environment. The thermal problem is especially realized in devices which have: little system mass which may absorb thermal energy, no capacity to transfer thermal energy to the system's external environment, and systems which are required to dissipate large amounts of heat for short periods of time. For many of the aforementioned applications the required operational life of the electronics do not exceed several minutes. In addition to the dissipated thermal energy of the MMIC's the host system itself may be generating heat through rocket or salvo burns, air friction, or the operation of thermal batteries. Several techniques have been used in the past to operate MMICs in a thermal environment as described above. Among these approaches are: the use of High Thermally Conductive Package Material or Heat Pipes to draw heat away from MMIC's, the inclusion of Temperature Compensating Circuits to stabilize performance, the inclusion of Thermo-electric Cold Plates, or to allow the device to operate at junction temperatures up to the theoretical failure point.

Typically, the subject applications do not realize the full advantage of heat pipes or high thermal conductive packaging material on the presumption that the small system size does not allow a cool zone which may collect thermal energy. Although the use of these techniques will aid in effectively spreading the heat, all dissipated thermal energy remains in the form of heat. Similarly, the stated applications typically have, limited space and available power which precludes the use of temperature compensating circuits and thermo-electric cold plates. Although allowing MMIC's to operate up to their theoretical junction temperatures does provide relief to the thermal problem, the effects on system performance are usually intolerable.

This paper presents an innovative temperature stabilization concept for MMIC's. The feasibility of maintaining MMIC junction temperatures within established operational limits for extended periods of time will be demonstrated. Experimental data is presented which supports the theoretical design principles which certify a significant increase in the operational life.

THEORETICAL DESIGN PRINCIPLES

The change of state which occurs when a substance is converted from a solid into a liquid is called fusion. The temperature at which this change of state takes place is dependent on the substance's molecular characteristics and the external (atmospheric) pressure. During fusion thermal energy is spent in over coming molecular cohesive forces. The substance in it's liquid phase, has a higher energy content then the same substance in it's solid phase. This additional energy is released back to the environment when the substance solidifies. The quantity of thermal energy which is absorbed during fusion is commonly referred to as the "Latent Heat of Fusion" and is a constant for a given substance at a given pressure.

The presence of impurities within a substance has the effect of lowering the temperature at which the substance will under go a phase change. In general, a substance with impurities solidifies over a range of temperatures. In this range of temperatures various alloys will exist, each having it's own phase change temperature. The alloy with the lowest liquidous temperature is known as a eutectic, as it solidifies or liquifies, all components of the alloy remain proportional. Eutectics under go a phase change at a single temperature, the substance's temperature will remain constant while the phase change is taking place. The time required for the phase change is proportional to the mass of the material undergoing the phase change and the quantity of the applied thermal energy. It is this property which stabilizes the MMIC's operating temperature.

Assuming that a MMIC, which dissipates one watt, is mounted on one cubic centimeter of aluminum and that the MMIC and aluminum block are thermally isolated from the external environment (ie. all dissipated power remains in the system). It is desired that the system operational temperature dose not exceed 109 degrees centigrade. Negating the presence of the MMIC's mass as a thermal energy storage device and using 30 degrees centigrade as a initial temperature, the operation time, t1, to maximum system temperature is calculated as follows:

$$t1 = \frac{m\ Cp\ (\ Tf\ -\ Ti\ )}{P} \qquad [\ 1\ ]$$

where:

m = mass (2.68×10^{-3} kg)
Cp = Specific Heat (905.0 J/kg C)
Tf = Final temperature (109 C)
Ti = Initial temperature (30 C)
P = Power (1 W)

therefore: t1 = 191.6 s

If the system is altered to include 0.75 cubic centimeters of a eutectic alloy consisting of 67% Bi and 33% In (liquidous temperature 109 C), in place of an equivalent volume of aluminum, the new operational time, t2, is now calculated as follows:

$$t2 = t3 + t4 \qquad [\ 2\ ]$$

where:

t3 = time to heat aluminum and alloy

$$t3 = \frac{(m_{Al}\ Cp_{Al} + m_A\ Cp_A)(Tf - Ti)}{P} \qquad [\ 3\ ]$$

where:

m_{Al} = mass of aluminum (6.70×10^{-4} kg)
Cp_{Al} = Specific Heat Al. (905.0 J/kg C)
m_A = mass of alloy (6.66×10^{-3} kg)
Cp_A = Specific Heat alloy (176.8 J/kg C)
Tf = Final temperature (109 C)
Ti = Initial temperature (30 C)
P = Power (1 W)

therefore: t3 = 140.0 s

and:

t4 = time to melt alloy

$$t4 = \frac{m\ L}{P} \qquad [\ 4\ ]$$

where:

m = mass (6.6×10^{-3} kg)
L = Latent Heat Fusion (4.304×10^{4} J/kg)
P = Power (1 W)

therefore: t4 = 284.0 s

therefore: t2 = 424.0 s

The temperature rise as a function of applied power verses elapsed time for the two configurations described above is shown graphically in figure 1. The 424 seconds of operational life of the configuration which includes the eutectic alloy represents a 220% increase over the solid aluminum configuration.

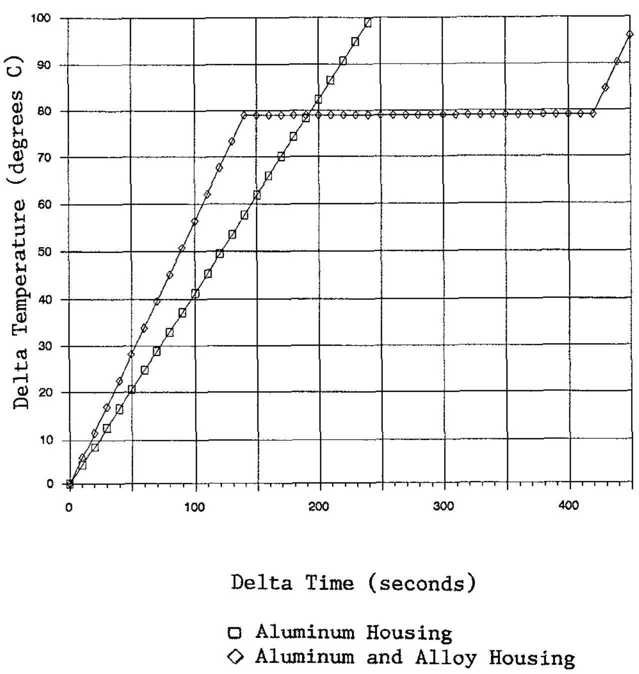

Figure 1. Theoretical Temperature Rise

EXPERIMENTAL RESULTS

Two RF aluminum housings, configured as shown in figure 3 were evaluated for their thermal performance. The housing illustrated in figure 3a. represents a typical MIC, solid aluminum configuration. The curve identified as Aluminum Housing Theoretical in figure 2 plots the theoretical change in temperature with respect to power as a function time for the typical MIC configuration. Plotted values were calculated using equation [1] and a housing mass, m, of 9.2 grams. Similarly, the curve identified as Aluminum and Alloy Housing Theoretical of figure 2 shows the theoretical change in temperature with respect to power as a function time for the modified MIC configuration shown in figure 3b. Although this housing is identical to the housing shown in figure 3a, it has been modified to include a cavity beneath the MMIC mounting area. This cavity has been filled with a phase change alloy and sealed. The plotted values were calculated using equations [2], [3], and [4] with a housing mass, mA_1, of 5.7 grams and a phase change alloy mass, m_A of 4.0 gram. The curves Aluminum Housing Experimental and Aluminum and Alloy Housing Experimental show the experimental results for the typical MIC and Modified MIC configurations respectively.

It is noted that the experimental change in temperature is characteristically lower than that which was theoretically calculated. Two physical properties which were not considered may account for the discrepancy. The calculations presented above consider the housing as a thermal system in equilibrium, no consideration has been given to the thermal gradient which is present during temperature transitions. The thermal gradient is a result of the material's thermal resistivity. It is this property which causes the phase change to start prior to, and have a duration longer than, the theoretical curve. Secondly, no considerations has been given to the convective cooling which is present in the experimental set up. The presence of convective cooling causes the temperature/time curve to roll off at higher temperatures.

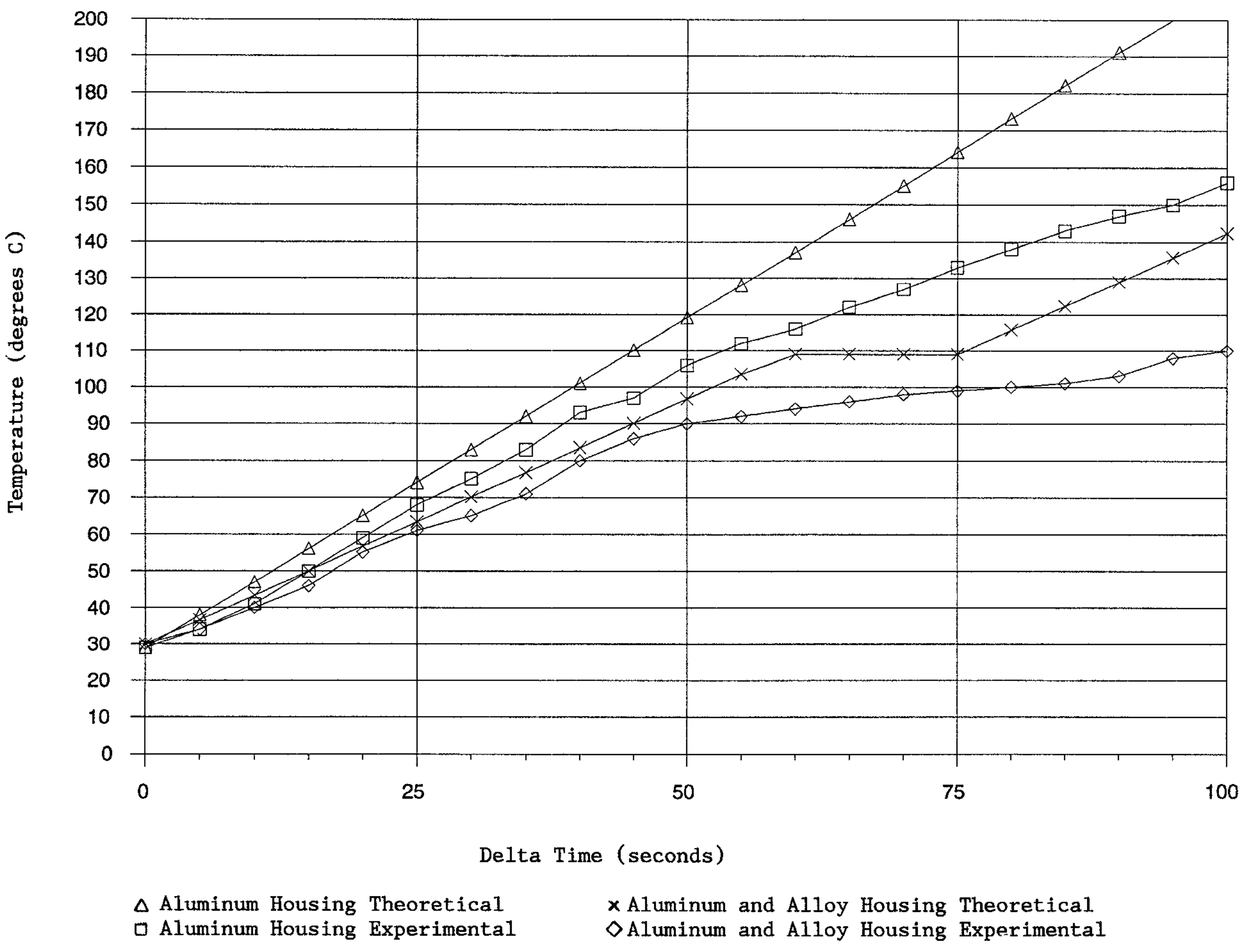

Figure 2. Experimental and Theoretical Data

(a) Typical MIC Housing

(b)Modified MIC Housing

A MIC Housing (Aluminum)
B Microstripe
C Active Device (MMIC)
D Temperature Probe
E Phase Change Alloy
q Thermal Energy

Figure 3. Housing Configurations

Because identical housings were used in the evaluation, the net result of the thermal gradient and convective cooling may be negated by examining the delta change in temperature between the two configurations. The result of this comparison, as well as a comparison of the theoretical values, are presented in figure 4.

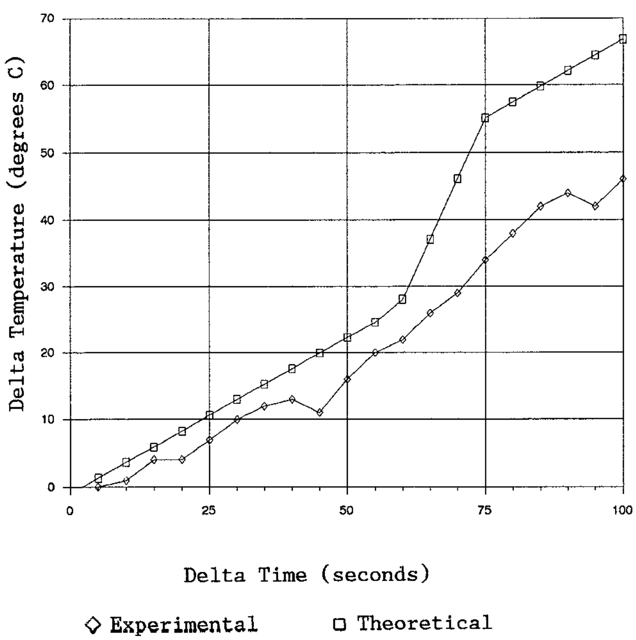

Figure 4. Delta Temperature Rise

CONCLUSION

In this paper an innovative temperature stabilization concept for MMIC's utilized in applications such as Decoys, Kinetic Energy Weapons, Missile Systems, and Smart Munitions has been presented. It has been demonstrated that MMIC junction temperatures will remain within established operational limits while a substance in close thermal proximity undergoes a change of state. Results have been shown which demonstrate an increases in operational life of approximately two hundred percent.

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