Heat sinking through socket contact technologies

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The classic function of a socket is to provide a connection mechanism from the integrated circuit (IC) to the circuit board with as little electrical load as possible. This allows the IC to function as it is soldered into the PCB (printed circuit board) but can be replaced by another IC to upgrade or test multiple ICs. With the advent of power devices getting into the tens of watts, perhaps even 50-100W, the socket needs to accommodate removal of the heat due to this power, or the IC will self destruct, or worse. For the most part, heat is removed from the top side of the device by adding fins/plates with air circulation. With the introduction of quad flat no-leads (QFN) packages and quad flat packages (QFP) with exposed pads (ePad), heat needs to be removed from the bottom side as well. Power devices are designed such that the center pad acts as both electrical grounding and as a medium for thermal dissipation. When soldered down, heat from the center pad is dissipated via the PCB ground copper plane layer. When placed inside the socket, heat has to pass through the socket contact. This article describes experimental methods to determine heat dissipation through socket contact technologies.

Socket overview

Two of the most common high-frequency contactors for a socket are elastomer and spring pin with bandwidths of >40GHz and <30GHz, respectively. The socket comprises contactors that interconnect QFN pads to the target PCB pads. The socket body has alignment features that precisely place the IC over the contractors and the socket lid has a compression mechanism to apply the down force to compress the QFNs into the contactors. In a high-power application, the compression mechanism needs to perform double duty by also acting as a heat sink that pulls the heat out of the IC. A backing plate on the bottom side of the PCB may be needed to provide the rigidity for the contactors to work reliably. This need is dependent on the size of the chip, the required flatness, PCB material, and PCB thickness. In addition to the heat dissipation from the top side, there is some amount of heat dissipated through the socket contacts down to the PCB. Depending on the chip design, function, and construction features, heat dissipation through the bottom side via socket contact down to the PCB is very critical. A methodology was developed to measure and understand heat dissipation through the various socket contact technologies.

Modes of heat transfer

Heat transfer can be defined as the transmission of energy from one region to another as a result of a temperature difference. Heat conduction is a property of matter that causes heat energy to flow through the matter. Heat convection is due to the property of moving matter (naturally or under force) that is able to carry heat energy from a higher temperature region to a lower temperature region. Heat radiation is the property of matter such that it is able to emit and absorb different kinds of electromagnetic radiation. Any energy exchange between bodies occurs through one of these modes or a combination of them. We have focused on heat conduction through various socket contact technologies. An experiment was added to compare conduction versus radiation effects in the socket contact heat dissipation process as well.

Thermal resistance

Thermal resistance is the temperature difference, at steady state, between two defined surfaces of a material or construction that induces a unit heat flow rate through a unit area. Thermal resistance is the critical parameter in our experiment and is directly proportional to the thickness of the material, and inversely proportional to the thermal conductivity of the material. In our experiment, thermal resistances of various socket contact technologies are measured. Thermal resistance can be calculated as shown in **Equation 1**:

$$Tr = (T1-T2)/P \quad \textbf{(Eq. 1)}$$

where:

Tr = Thermal resistance of the socket contact in °C/W;
T1 = Top side temperature in °C;
T2 = Bottom side temperature in °C; and
P = Power dissipation in W.

Experimental setup #1

Three different socket contact technologies were considered for this experiment: 1) embedded gold-plated wire inside the elastomer contact (SG), 2) stamped spring pin contact (SBT), and 3) embedded silver ball column inside the elastomer contact (SM).

The SG elastomer comprises a fine-pitch matrix (0.05 x 0.05mm) of gold-plated wires (20µm diameter) that are embedded at a 63° angle in a soft insulating sheet of silicone rubber. The insulation resistance between connections with 500VDC is 1000Mohms—it is ideal for high-current (50mA per filament) applications where a thin, high-density anisotropic connector is required. The gold-plated brass filaments protrude several microns from the top and bottom surfaces of the silicone sheet. The operating temperature range for the SG elastomer is -35 to +100°C. When compressed using the socket mechanism, multiple gold-plated wires from the SG elastomer connect the IC surface pads to the bottom PCB pads.

The SM elastomer is a unique contact that has precise silver balls held together by a proprietary conductive formulation. These conductive columns (diameter optimized for 50 ohm impedance) are suspended in a nonconductive flexible elastomer substrate with a patented solid core for enhanced durability and reliable performance over time, temperature, and cycles. This flexible substrate is compliant and resilient – qualities that enable the conductive columns to revert back to their original shape when the force is removed. When compressed by an external force, silver particles inside the column connect with each other. This creates an electrical path, which in turn connects the IC surface pads to the bottom PCB pads. The insulation resistance between silver columns with 500VDC is 1000Mohms. The typical contact resistance is 20milliohms per silver column, and the current carrying capacity is 4A.

The SBT contact is a stamped contact with an outside spring, as well as an inside leaf spring that provides a robust solution for low-contact resistance. SBT contact technology has a three part system that includes a top plunger, a bottom plunger, and a spring. The beryllium copper plungers are stamped and assembled to a stainless steel spring that provides optimum force. The insulation resistance between SBT contacts is provided by PEEK plastic. When 500VDC was applied between SBT contacts, a resistance of 1000Mohms was measured. The typical contact resistance is 30milliohms per SBT contact, and the current-carrying capacity is 8A.

The heat source is supplied by an HT15W 1/8”x1/2”, 15W heating element rod. The HT15W is a miniature 15W cartridge heater that can be used for many applications requiring small areas to be heated. When voltage is applied between the leads, heat is generated at the lead exits. The heater element is calibrated by supplying 6V, 12V, 15V, 20V, and 24V. The values of the corresponding wattage generated were documented. After calibration, this heater element is integrated into the top of the compression plate slot inside the socket (**Figure 1**). One thermocouple was installed on top of the socket contact, and the other thermocouple was installed on the bottom of the socket contact. The socket lid is closed and a downward force is applied by turning the central compression screw (see **Figure 2**). The temperature reading in **Figure 2** shows 28°C as there is no heat generated. When voltage is applied to the heater element, heat is generated. The initial applied voltage is 6V and the corresponding power reading is 0.9W. Temperature data is collected after steady state is reached as indicated on both of the thermocouples. Using the formula in **Eq. 1**, the thermal resistance is calculated. Similarly, thermal resistance data is calculated for various power levels by changing the applied voltage. The data is presented graphically in **Figure 2** with the power applied shown on the X-axis, and thermal resistance on the Y-axis. The experiment is then repeated for the other two socket contacts.

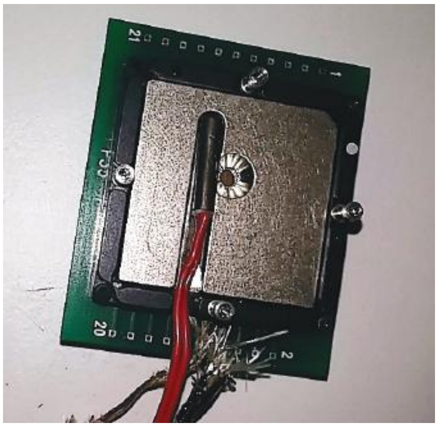

Figure 1: Experimental setup showing the heater element rod integrated into the socket compression plate.

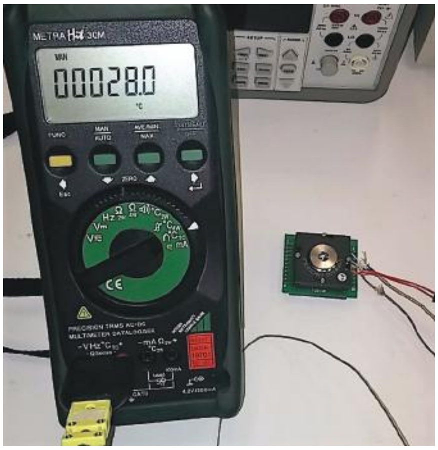

Figure 2: Experimental setup showing the compressed socket with heater element rod connected to a power supply and a thermocouple connected to a multimeter.

Results and discussions #1

Thermal resistance curves are represented in graphical format for three socket contact technologies in **Figure 3**. It can be seen from the graph that the SG contact (i.e., the blue-colored curve) has low thermal resistance at a low power of 1-4W. Heat passes through the contact with very low resistance. Around 5W, the temperature change is approximately 3°C/W; this means the total temperature rise is 15°C for 5W of power. The SG contact maximum operating temperature is 100°C. If the IC’s rated power is 5W, then the SG socket maximum operating temperature is reduced to 85°C on account of the thermal resistance phenomenon. Otherwise, the SG contact will be damaged by overheating.

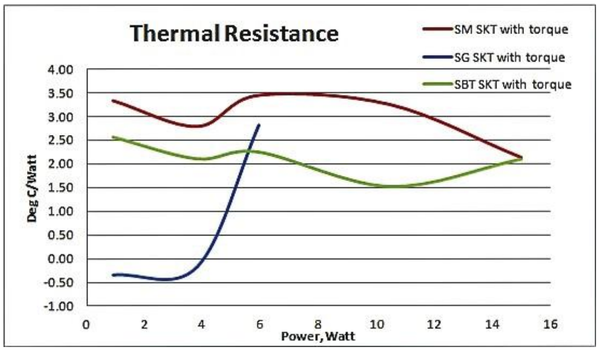

Figure 3: Comparison of thermal resistance for three different socket contact technologies.

The SM socket curve is shown in red (**Figure 3**) and has a high thermal resistance at low power. The thermal resistance got better at a higher power value, e.g., at 15W. In the SM socket, the thermal conductive path is through silver particles. With low heat, the temperature difference is 3.5°C for 1W. Heat passes through various small silver particles before it reaches the other end. With high heat, the temperature difference is 2°C/W at a power level of 15W. At higher temperatures, the silver particles expand, which causes the contact between particles to be more efficient. This allows the smooth flow of heat causing a drop in thermal resistance. The SM contact maximum operating temperature is 155°C. At 15W of power, the thermal resistance is 2°C/W, and the

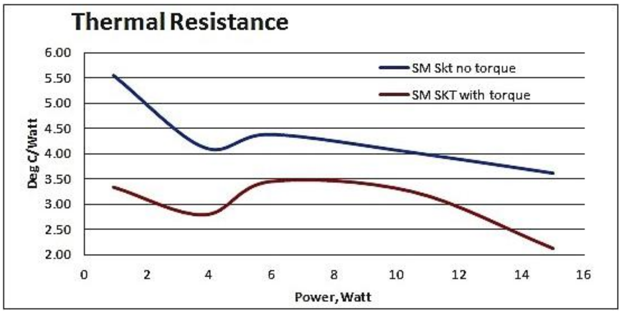

Figure 4: Comparison of conduction versus radiation phenomena when heat is dissipated through socket contact technology.

temperature rise is 30°C. The SM contact can be operated in an environment up to 125°C when the IC power is 15W.

The SBT socket curve is presented in green in **Figure 3**. It is an almost flat curve showing a thermal resistance between 2.5°C and 2°C. The SBT contact is made of a copper alloy with an external spring. The length of the contact is 2.5mm and it has a rectangular cross section of 0.2x0.6mm. The thermal resistance is inversely proportional to the cross sectional area and directly proportional to the length. Because the SBT contact has a uniform cross sectional area, the change in thermal resistance is very minimal due to the power change between 1W and 15W. The maximum operating temperature of the SBT contact is 180°C. At 15W of power, the thermal resistance is 2°C/W, and the temperature rise is 30°C. The SBT contact can be operated in an environment of up to 150°C when the IC power is 15W.

Experimental setup #2

Contacts will transfer heat when compressed—this is a conduction phenomenon. When not compressed, there is some heat transferred due to radiation. The SM contact alone was used for this experiment in order to compare heat transfer through conduction vs. through radiation. The experimental setup is the same as the previous one. Two SM sockets were used for this purpose. One SM socket is compressed by applying the recommended torque to the compression screw. The second SM socket is not compressed. The thermal resistance data was calculated for various values of power by changing the applied voltage for both of the SM sockets. **Figure 4** shows the data is presented graphically with the power applied shown on the X-axis, and the thermal resistance on the Y-axis.

Results and discussions #2

In **Figure 4**, it can be seen from the graph that the two curves are very similar with an offset in thermal resistance values. The compressed SM socket shows a thermal resistance from 3.5-2°C. The SM socket (not compressed) shows a thermal resistance from 5.5 to 3.5°C, which is an indication of the amount of heat transferred through radiation. Heat transfer caused by emission of electromagnetic waves is known as thermal radiation. Heat transfer through radiation takes place in the form of electromagnetic waves - mainly in the infrared region.

Summary

Thermal management of a QFN socket is an all-inclusive method involving the material selection, design, analysis, optimization and verification of a cooling system both on the top side via a heat sink and an axial flow fan, and on the bottom side via a socket contact technology for the purpose of producing a reliable socket for testing high-power devices. In the above discussion, heat dissipation through various socket contact technologies were compared over a range of power dissipation values. Also, the heat dissipation of various socket contact technologies is compared with conduction and radiation phenomena. For high power, SM and SBT contacts provide better heat dissipation through the PCB side. For low power, the SG contact has the lowest thermal resistance. The socket selection process typically involves parameters, such as electrical bandwidth, contact resistance, current capacity, temperature range, etc. Based on the above discussion, the thermal resistance of the socket contact plays a significant role when considering contact selection.

Acknowledgement

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Biography

Mr. Ila Pal received his MS degree in Mechanical Engineering from Iowa State U., and an MBA degree from the U. of St. Thomas; he is COO at Ironwood Electronics Inc., USA; email ila@ironwoodelectronics.com