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Modern miniature IC packages have allowed great space savings in products, but frustrate the designer by concentrating the heat generated by circuits into smaller volumes. Increasing IC speeds and complexities over the years have also demanded greater power dissipation. Higher internal operating temperatures will shorten the life of an IC; elevated but safe temperatures often reduce the quality of performance in circuits, for instance degrading frequency response or distortion.

To cope with the problem, a variety of heat management packages have been introduced which conduct heat from the IC die through the package leads to the circuit board. The board becomes the major heatsink, and the onus of thermal design passes from the IC manufacturer to the board designer. This article is intended to assist the board designer in measuring thermal resistance of mounted IC devices efficiently.

Traditional parameters θ_{JA} (thermal resistance of a device not connected to anything) and θ_{JC} (infinite heatsink connected to the part) are not useful with mounted devices. Circuit boards are neither insignificant nor infinite heat sinks. We will use the parameter θ_{JM} as the mounted thermal resistance of an IC, and it will vary with die size, package type, and circuit board features. The θ_{JM} can be estimated by thermal simulation of the part and its mounting environment, but seldom is there concrete data on the thermal structure of the IC, and correctly modeling the board environment is difficult. A good way to estimate θ_{JM} is to solder the IC to an area of circuit board that has been suitably sculpted with a Dremel tool to emulate a final board pattern in the region of the test device (or a finished board itself) and use the following circuit to measure θ_{JM} :

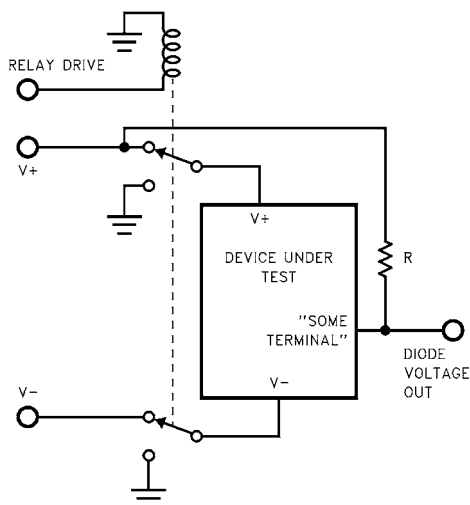


FIGURE 1.

"Some terminal" is any pin that is connected to an internal parasitic diode whose other connection is either power supply pin. The IC manufacturer's technical support people can help select the right pin and drive polarity. We will use the forward voltage as a measure of internal die temperature. When the relay grounds the supply pins, R provides a current from a supply to bias the diode. Depending on the internal diode connection, V+ or V- will be connected to R. R should supply a current low enough to create minimal resistive drop in series with the diode. 50µA is a good guess for the current, or any current that sets up about 600mV of forward diode voltage at room temperature. The general equation for diode tempco (it generally need not be measured directly) is:

$\Delta V/\Delta T = -(1.12V - V_{be}(25^\circ C))/300^\circ K$. Thus a 600mV junction at room temperature has a -1.7mV/°C temperature coefficient.

Using a storage or digitizing oscilloscope measuring the forward diode voltage, we will observe the thermal relaxation of the die after a steady power dissipation is terminated. The dissipation is the part's own supply current, applied through the relay. The relay's drive is also the oscilloscope trigger. Because the temperature change may only cause tens of millivolts of diode voltage variation against the background of 600mV, a stable differential-amplifier with adjustable offset will be used for the oscilloscope input. Alternately, the ground of the above circuit may be shifted with a third supply before being connected to the oscilloscope.

This is the test sequence:

1. Connect everything with the device powered down. Set the oscilloscope sweep to the slowest setting, continuously sweeping.
2. Adjust the offset against the diode voltage to center the oscilloscope trace. The 10mV/div. sensitivity is a good start.
3. Apply power to the device via the relay. The oscilloscope trace will be off-screen. Allow the part at least ten minutes to warm up its mounting.
4. Clear any stored trace. Turn off power to the device. The following trace should be seen on the oscilloscope:

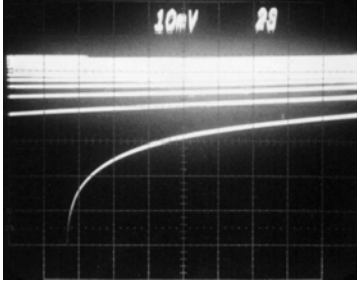


FIGURE 2. OSCILLOSCOPE DISPLAY OF DIODE VOLTAGE RELAXATION DURING COOLING

We see an initial rapid cooling followed by very slow settling back toward room temperature. The cooling rate is not a simple exponential decay, but has a wide range of time dynamics. Here is the decay behavior of an EL1501 mounted on a large heat spreader:

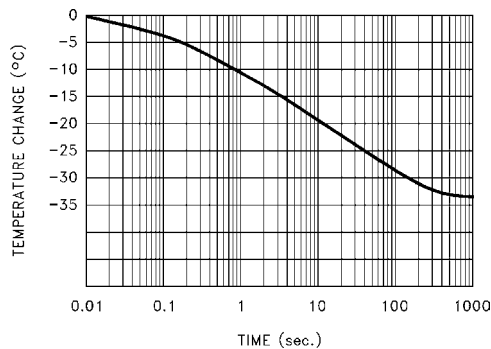


FIGURE 3. THERMAL RELAXATION vs TIME OF A MOUNTED POWER SO-20 PACKAGE

For the first ten milliseconds little die temperature change occurs. Then the heat makes its way through the die and flows out through the leadframe, which occurs in around ten seconds. The last event is the settling of the heat-sinking board, which resolves in ten minutes. Clearly, thermal measurements require patience and time.

The thermal resistance θ_{JM} is then the temperature variation (long-term) divided by the power dissipated, so:

$$\theta_{JM} = T_{\text{diode}} / P_{\text{diss, quiescent}}$$

$$= \frac{\Delta V_{\text{diode}} \times 300^{\circ}\text{K}}{P_{\text{diss, quiescent}} \times (1.12\text{V} - V_{\text{BE}}(25^{\circ}\text{C}))}$$

Using this technique, the thermal resistance of the SOL-20 fused-lead package was measured. This package houses the EL1501 and has four center leads on each side fused to the IC's mounting header. Thus, heat flows directly through these pins from the IC and spreads through the ground plane on top of the circuit board. A nearly continuous ground

plane is hand-drawn. Several variations of the board were tested. The first was the most straightforward: just the top foil is a heatsink. By cutting away board material, a variable area was implemented and thermal resistance measured. Then the measurements are repeated on an identical board with no solder mask to add to thermal resistance. Another variation was to create another heatsink area on the back of the board, thermally connected to the top foil by a multitude of feedthroughs. Finally, a copper sheet-metal heatsink was soldered to the top foil near the IC's heat-spreading pins.

The results are shown in this graph:

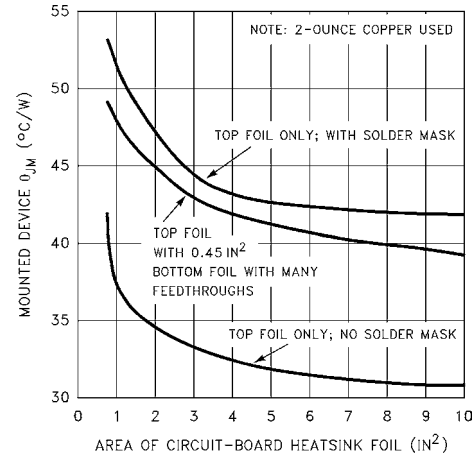


FIGURE 4. THERMAL RESISTANCE OF DUAL-4-FUSED-LEAD SOL-20 PACKAGE

The SO-20 standard package has a θ_{JA} of 80°C/W . With 4in^2 of circuit board heatsink copper with solder maskcutout, the thermal resistance drops to 32°C/W . Given a quiescent dissipation of 1.25W , the die temperature rise of the mounted EL1501 is 40°C . With a maximum ambient temperature of 85°C , we have a worst-case die temperature of 125°C , safely within the 150°C package limit.

Some observations:

1. 4in^2 of copper area is sufficient in that more doesn't help much.
2. The bottom foil did not greatly help.
3. Removing the solder mask over the heat spreading area, if appropriate, reduces θ_{JM} nicely.

Finally, a large metal heatsink mounted close to the heat-spreading pins produced a θ_{JC} of 30°C/W .