APPLICATION NOTE 953

More Power from HEXDIPs™

(HEXDIP and HEXFET are trademarks for International Rectifier Power MOSFETs)

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International Rectifier's HEXDIP power MOSFET, a 4-pin dual in-line package (DIP), offers an attractive alternative to the TO-220 or TO-39 packages for low power printed circuit mount applications. The HEXDIP (Fig. 1), for example, offers greater packing density and lower price advantages than either the TO-220 or TO-39.

In the past the HEXDIP has been passed up in some applications because the user needed slightly more than 1 Watt, or the application required 1 Watt of dissipation at elevated ambient temperatures. In other applications the 1 Watt rating was fine for normal operation, but the devices would be subject to brief overload conditions of greater than 1 Watt. Until now, the HEXDIP user has been stuck with an $R\Theta_{JA}$ of 120° C/Watt with apparently no way of bettering that figure by heatsinking.

The intent of this application note is to show that the $R\Theta_{JA}$ of the HEXDIP can be substantially improved under practical operating conditions.

$R\Theta_{JL}$ of HEXDIPs

The drain of the HEXDIP is carried out of the package by two of the four leads of the device. These leads are joined together above the point where they would extend through a pc board and actually form a tab. Inside the package the chip is mounted directly to this drain tab. Consequently the HEXDIP has a $R\Theta_{JL}$ (Junction-to-Lead Thermal Resistance) capability similar in nature to a common axial lead rectifier.

The heatsinking capabilities of the drain tab decrease with increased distance from the case. The optimum $R\Theta_{JL}$ capability at the minimum possible distance from the case, is 20° C/Watt. Interesting but impractical. However, for a typical top solder pc mount or $\simeq 0.159$ inches from the case, the $R\Theta_{JL}$ is 30° C/Watt. For a bottom solder situation at $\simeq 0.218$ inches from the case, the $R\Theta_{JL}$ only increases to 40° C/Watt. These $R\Theta_{JL}$ values seem encouraging, but this is not the whole story.

Getting the Heat Out

In a typical application, the drain tab will be soldered to a pc board pad (or trace). The total $R\Theta_{JA}$ (junction-to-lead + lead-to-ambient) of the device is inversely proportional to the pad surface area. Additionally, moving air across the pc pad and the device can give dramatic reductions in $R\Theta_{JA}$.

International Rectifier has characterized various pad sizes versus air velocity for the $R\Theta_{JA}$ of the HEXDIP. Figure 2 shows the results for top and bottom solder.

The graph in Figure 2 is only a starting guideline for $R\Theta_{JA}$ versus pad size. The pad sizes seem overly large. A tiny HEXDIP mounted in the middle of a gigantic 1" diameter copper pad seems ridiculous (and is). However, in a practical application, there is usually a fair amount of unused pc board space. This extra space may be taken up by ground plane, voltage buss, or just left empty. With a little forethought this extra board space can sometimes be utilized for heatsinking the HEXDIP. The shape of the drain mounting pad is not overly critical. The idea is to spread the pad around wherever there is room. Once all the possible territory has been used additional advantage can be gained by placing other traces of substantial size in close proximity to the drain pad. Typical board material provides poor thermal conductivity, yet a substantial amount of heat can be transferred through the board to neighboring copper traces.

Transient Thermal Impedance in HEXDIPS

Certain applications may require the HEXDIP to withstand high power dissipation for brief periods of time. For instance, a motor may only draw a small amount of current to run but a very large current during acceleration or a momentary fault condition. Some circuit designs may even force a "switching" device into the linear mode during these "overload" conditions causing many times more than the usual power dissipation in the device. The $Z\Theta_{JC}$ of a heatsinkable power device is evident, but a HEXDIP mounted on a printed circuit board has a $Z\Theta_{JA}$ which may be very useful to some applications.

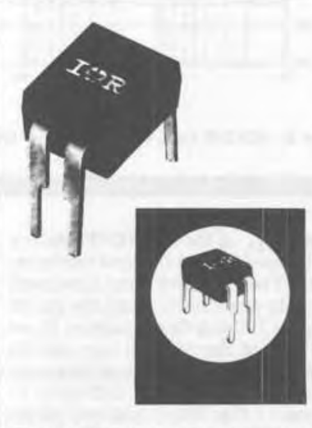

Figure 1. HEXDIP 4-Pin Dual In-Line (DIP) Package.

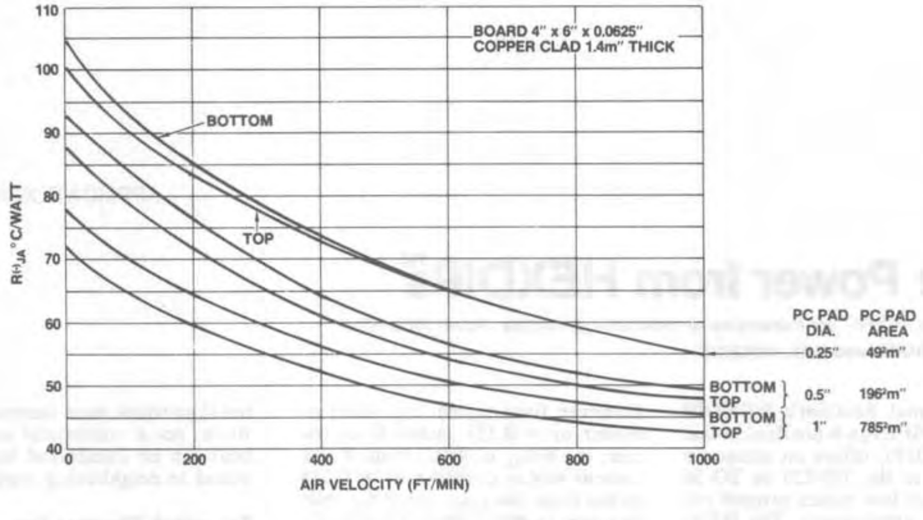

Figure 2. $R\Theta_{JA}$ vs. Air Velocity Top and Bottom pc Mount.

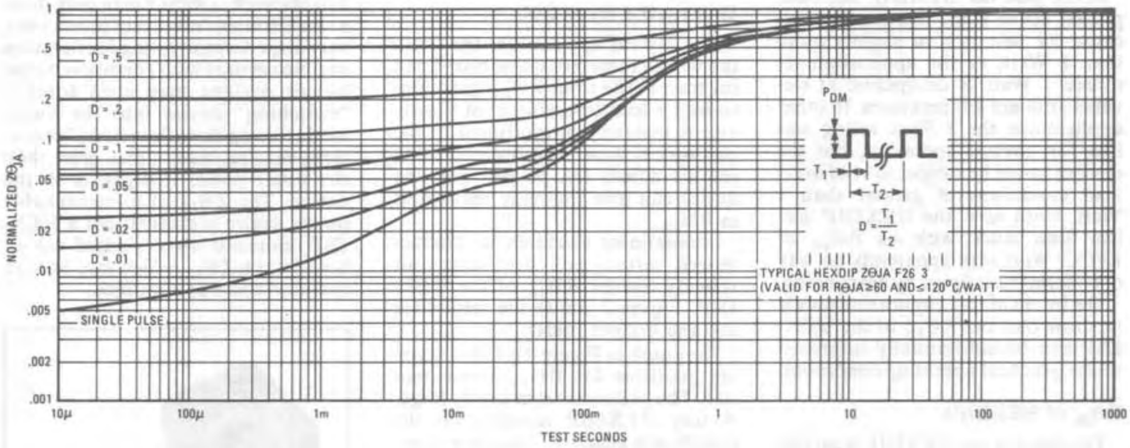

Figure 3. HEXDIP $Z\Theta_{JA}$ (typical). (Valid for $R\Theta_{JA} \geq 60°$ C/Watt or $\leq 120°$ C/Watt.)

The $Z\Theta_{JA}$ of the HEXDIP spans a number of different thermal time constants. Two of these time constants are easily discernable from the graph in Figure 3. From 10 µs to about 30 ms the shape of the curve is very similar to the $Z\Theta_{JC}$ curves common for power devices. The only basic difference at this point is that the normalized values are much lower than normally found in a TO-3 or TO-220 type of device. During this 10µs to 30 ms period, $R\Theta_{JL}$ and the thermal mass of the HEXDIP case and drain tab predominate the measurement. From 30 ms to about 150 Sec what can be seen is primarily the effect of the $R\Theta_{LA}$ (drain lead-to-ambient) and the associated thermal masses of the pc drain mounting pad, pc board and air. With a HEXDIP amounted on a pc board the 10 µs to 30 ms normalized $Z\Theta_{JA}$ is relatively small. This is because $Z\Theta_{JA}$ is normalized to the total $R\Theta_{JA}$ which is relatively large.

Referring back to Figure 3, the effects of all of the above mentioned thermal time constants are fairly dramatic. A power MOSFET in a common TO-3 or TO-220 package may have a single pulse power rating at 100 ms which is 2, or at best 3 times the DC power rating. A HEXDIP has a 100 ms single pulse power capability, which is 10 times its DC power rating.

This corresponds to a 100 ms single pulse rating of between 10 and 20 Watts. (Curves in Figure 3 are conservatively valid for $R\Theta_{JA}$ between 60° C/Watt and 120° C/Watt.)

Practical Application

To demonstrate how some of the aforementioned guidelines could be practically utilized, the circuit shown in Figure 4(a) was constructed on the single side pc board shown in Figure 4(b). The function of the circuit is to generate a tracking negative supply from a positive supply of 10V to 15V DC. Certainly the circuit in Figure 4(a) is not a state-of-the-art design, but it does serve to demonstrate the increased power capability possible with HEXDIPs.

The IRFD9110 HEXDIP is rated at -0.7 Amps I_D. This is based on the free air power rating of 1W. The IRFD9110 in Figure 4(a) is required to carry -902 mA RMS at full load with a 10 volt supply. Top solder mounted on the pc board in Figure 4(b), the total $R\Theta_{JA}$ of the IRFD9110 was $\simeq$ 70.8° C/Watt. This $R\Theta_{JA}$ was the total during full load circuit operation which included other heat sources on the board (555, resistors, etc.). The total power dissipation in the IRFD9110 was 1.3 Watts. The junction temperature was a comfortable 117° C in still air. Based on the specified $R_{DS(on)}$ and $R_{DS(on)}$ versus temperature of the IRFD9110, the maximum I_D capability of the IRFD9110 in this set-up would be about -930 mA for a maximum dissipation of about 1.77 Watts.

The drain pad of the circuit board in Figure 4(b) was approximately 0.4 square inches or the equivalent of a 0.714" diameter pad. Referred to in Figure 2, the actual thermal performance of this circuit is better than anticipated by the drain pc pad size. The explanation is a simple one. All of the copper on the board and even the board itself contribute to lower $R\Theta_{JA}$.

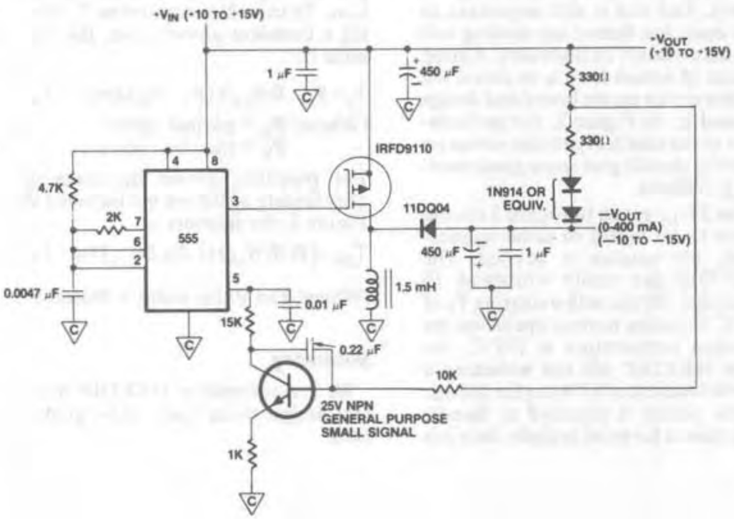

Figure 4(a). Schematic: Tracking Minus Supply.

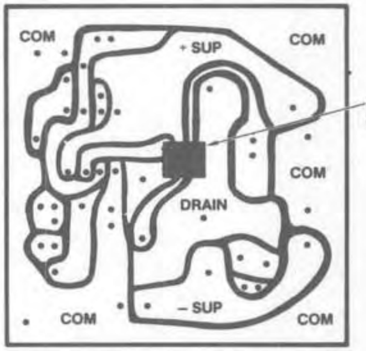

Figure 4(b). Circuit Board: Tracking Minus Supply. (Actual Size)

Getting Started

Thermal design with a power MOSFET in a package such as a TO-3 or TO-220 is very easy. $R\Theta_{JC}$, $R\Theta_{CS}$ and $R\Theta_{SA}$ can be summed up and maximum power dissipation calculated accordingly. Thermal design with the HEXDIP is not so easy, however. The graph in Figure 2 gives some good starting guidelines, but other factors such as pc board size, adjacent copper pc trace, and other heat sources on the board make breadboarding under actual (or nearly so) operating conditions a necessity.

The first step is to build the circuit up on a pc board. If there are multiple HEXDIPs on the board they should be included as should all other heat sources on the board. A good alternative to simulate multiple HEXDIPs may be to thermally bond artificial heat sources, such as resistors, to the board. The next step is to find the maximum junction temperature under worst case operating conditions (pad size, air velocity, T_A, etc.). The simplest way to measure T_J is to solder or epoxy a very small thermocouple to the drain tab as close as possible to the device package. Adding 30° C/Watt to the drain tab temperature results in a *very* conservative approximation of the junction temperature

To determine $R\Theta_{JA}$ total, the formula is:

$$R\Theta_{JA} = \frac{T_{DT} + (P \cdot 30) - T_A}{P}$$

(Where: T_{DT} = temperature of drain tab.)

With a linear circuit there is no need to control the ambient temperature to measure power. In a switching circuit the $R_{DS(on)}$ losses will increase with ambient temperature and, therefore, ambient temperature must be considered when calculating power dissipation for the final design.

In the case of many HEXDIPs on a board, all dissipating power, there can be problems. If there are 20 tightly packed HEXDIPs, each dissipating

1 Watt, a substantial portion of those 20 Watts will be conducted into the board. Pad size is still important in this case, but forced air cooling will almost certainly be necessary. A good course of action here is to locate the hottest device on the board and design around it. In Figure 2, the performance of the smallest pad size versus air velocity should give some good starting guidelines.

The $Z\Theta_{JA}$ graph in Figure 3 should prove to be useful to some applications, but caution is advised. The HEXDIP can easily withstand 10 Watts for 100 ms with a starting T_J of 25° C. If during normal operation the junction temperature is 100° C, the same HEXDIP will not withstand a power transient of 10 Watts for 100 ms. If the circuit is required to handle high power for brief periods, then it is advisable to design for the lowest practical T_J during "normal" operation. To calculate maximum T_J during a transient power pulse, the formula is:

$$T_J = P_N \cdot R\Theta_{JA} + (P_T - P_N)\, Z\Theta_{JA} + T_A$$

(Where: P_N = normal power
P_T = transient power)

For repetitive power transients of duty factors which are not included in Figure 3, the formula is:

$$T_{Jpk} = [D \cdot R\Theta_{JA} + (1-D) Z\Theta_{JA}]\, P_{pk} + T_A$$

(Where: D = Pulse width ÷ Period.)

Summary

We can summarize HEXDIP thermal design using some basic guidelines:

1. Make the pc drain pad as large as is practically possible, regardless of shape (Figure 2, Figure 4(b)).
2. Make adjacent copper trace as large as possible (Figure 4(b)).
3. Leave as much copper on the entire board as possible (Figure 4(b)).
4. Apply the above three steps using top and bottom of the board where applicable and by using the *minimum* possible spacing between traces.
5. Use the maximum practical air velocity (especially with multiple HEXDIPs on a board) (Figure 2).
6. Utilize the $Z\Theta_{JA}$ of the HEXDIP where applicable (Figure 3).
7. Test thermal performance of the HEXDIP under the most authentic operating conditions possible. ☐